PLUTO

ASTRONOMY

July 1986
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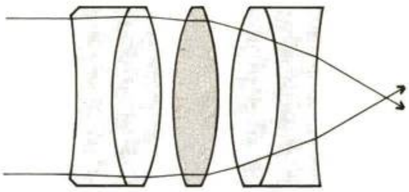
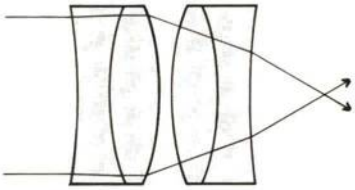


Meade 5-element Super Plössl design: the central lens element enables significant reductions in chromatic aberration and edge-distortions over other premium Plössl designs.



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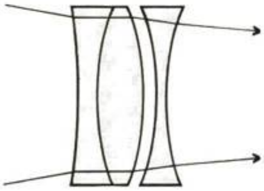

Meade Series 4000 Barlows: 3 elements, air-spaced, instead of the standard 2 non-air-spaced elements.

Series 4000 Eyepieces and Barlows

Super Plössls (5-elements)	APPARENT FIELD	BARREL DIA.	PARFOCAL
6.4mm	52°	1¼"	Yes
9.7mm	52°	1¼"	Yes
12.4mm	52°	1¼"	Yes
15mm	52°	1¼"	Yes
20mm	52°	1¼"	Yes
26mm	52°	1¼"	Yes
32mm	52°	1¼"	Yes
40mm	44°	1¼"	No
56mm	52°	2"	No
Super Wide Angles (6-elements)			
13.8mm	67°	1¼"	Yes
18mm	67°	1¼"	Yes
24.5mm	67°	1¼"	Yes
32mm	67°	2"	No
40mm	67°	2"	No
Ultra Wide Angles (8-elements)			
4.7mm	84°	1¼"	Yes
6.7mm	84°	1¼"	Yes
8.8mm	84°	1¼" & 2"	Yes
14mm	84°	1¼" & 2"	No
Barlow Lenses (3-elements, air-spaced)			
#140 2X Telenegative Amplifier		1¼"	Yes
#142 2.8X Telenegative Amplifier		1¼"	Yes

Meade 2" Mirror Diagonal: For attachment to Schmidt-Cassegrain telescopes, the 2" Mirror Diagonal permits use of Series 4000 eyepieces with 2" barrels. The 1/10-wave-flat Pyrex mirror, manufactured at the Meade Costa Mesa optical facility, is multi-coated with enhanced aluminum for maximum reflectance. An adapter for 1¼" eyepieces is included.

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Cover: During the past year, Halley's Comet has been followed by backyard stargazers around the world; it is now rapidly fading and will not appear bright for another seventy-five years. Photo by Gene and Carolyn Shoemaker, Palomar Observatory; courtesy Bobby Bus, Lowell Observatory. This month's feature article examines another infamous solar system object — Pluto. Since its discovery only fifty-six years ago, astronomers have learned so little about Pluto's history that many doubt it is actually a planet.

These pages: At its best, Comet Halley appeared as a 3rd-magnitude fuzzball with a 10° tail. Photo by Gregory L. Blount.

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Pluto

Enigma on the Edge of the Solar System

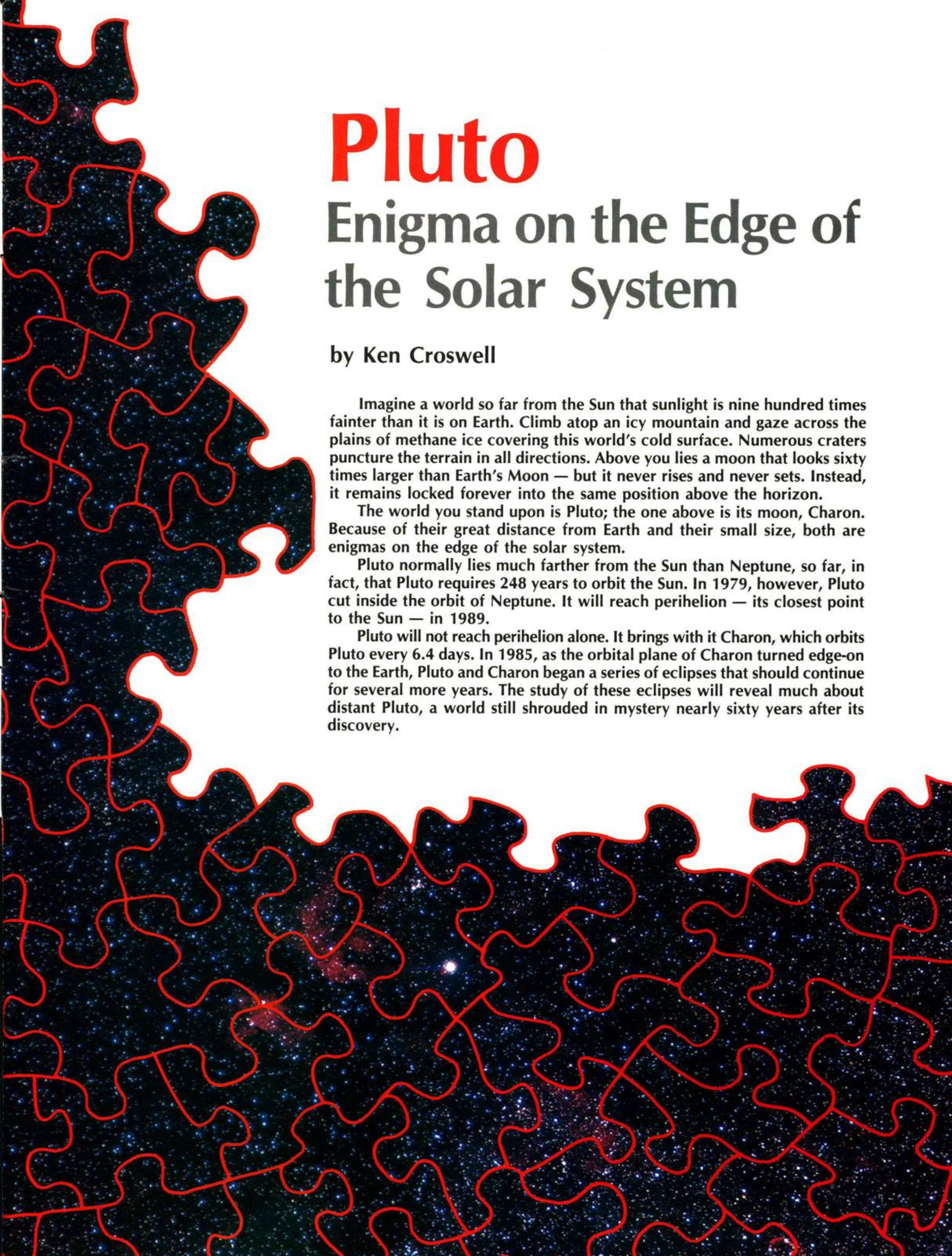
by Ken Croswell

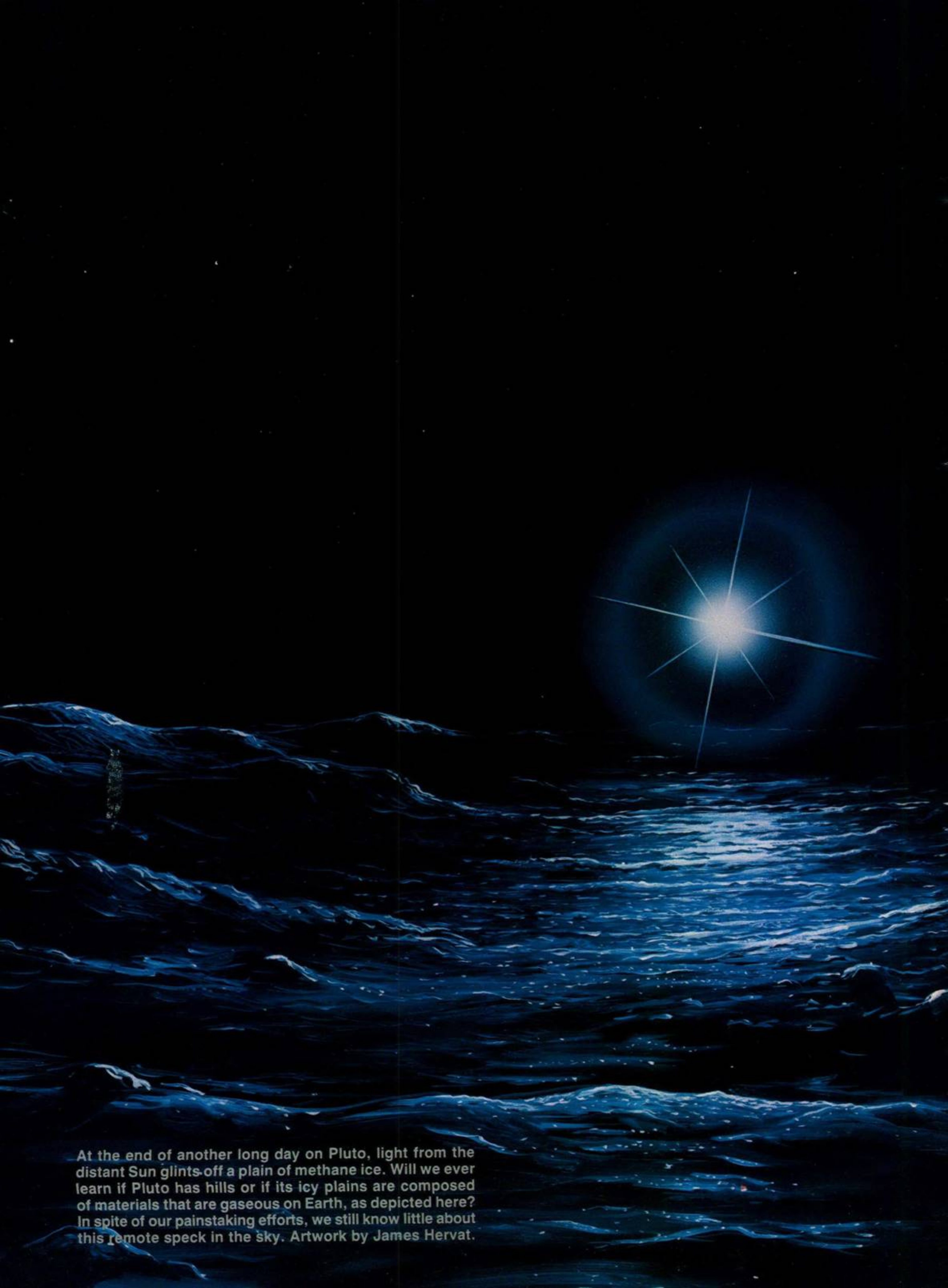
Imagine a world so far from the Sun that sunlight is nine hundred times fainter than it is on Earth. Climb atop an icy mountain and gaze across the plains of methane ice covering this world's cold surface. Numerous craters puncture the terrain in all directions. Above you lies a moon that looks sixty times larger than Earth's Moon — but it never rises and never sets. Instead, it remains locked forever into the same position above the horizon.

The world you stand upon is Pluto; the one above is its moon, Charon. Because of their great distance from Earth and their small size, both are enigmas on the edge of the solar system.

Pluto normally lies much farther from the Sun than Neptune, so far, in fact, that Pluto requires 248 years to orbit the Sun. In 1979, however, Pluto cut inside the orbit of Neptune. It will reach perihelion — its closest point to the Sun — in 1989.

Pluto will not reach perihelion alone. It brings with it Charon, which orbits Pluto every 6.4 days. In 1985, as the orbital plane of Charon turned edge-on to the Earth, Pluto and Charon began a series of eclipses that should continue for several more years. The study of these eclipses will reveal much about distant Pluto, a world still shrouded in mystery nearly sixty years after its discovery.





At the end of another long day on Pluto, light from the distant Sun glints off a plain of methane ice. Will we ever learn if Pluto has hills or if its icy plains are composed of materials that are gaseous on Earth, as depicted here? In spite of our painstaking efforts, we still know little about this remote speck in the sky. Artwork by James Hervat.

The Discovery of Pluto

Although a member of the outer solar system, Pluto has little in common with its neighbors in space, Uranus and Neptune. Pluto is completely unlike Neptune, yet it was Neptune that inspired the search for Pluto.

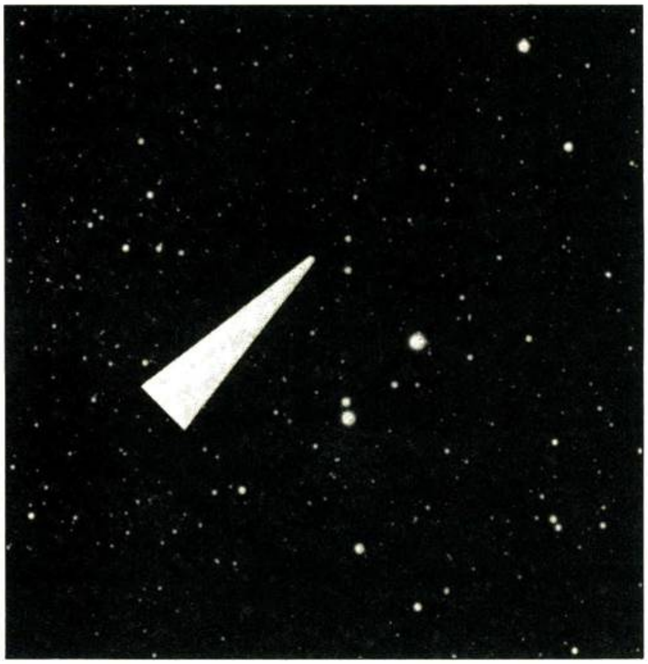
While Uranus had been found by chance, the discovery of Neptune was a triumph for theoretical astronomy. Neptune is so massive that its gravity perturbs the motion of Uranus. In 1845 and 1846, English mathematician John Couch Adams and French astronomer Urbain Leverrier independently analyzed the deviations in Uranus' motion and predicted the position of an unseen planet. In September 1846, German astronomer Johann Galle discovered Neptune.

The planet lay within a degree of Leverrier's position and within one and one-half degrees of Adams' prediction. Although Adams and Leverrier had positioned the planet correctly, they got everything else about it wrong, overestimating Neptune's distance by 20 percent, its mass by a factor of two, and its orbital eccentricity by a factor of ten.

Several decades later it became obvious that Neptune could not fully explain the deviations observed in Uranus' motion. The American astronomers William Pickering and Percival Lowell argued that the discrepancy could be the result of another planet located even farther from the Sun than Neptune. They launched separate theoretical and observational efforts to find this object, which Lowell called Planet X and Pickering Planet O.

Lowell's initial search for the new planet occurred between 1905 and 1909. Though it proved unsuccessful, it caused Lowell to think carefully about the situation before him. For Adams and Leverrier, Neptune had been the solution; for Lowell it was part of the problem. Neptune's orbit was not known precisely, so Lowell could not use deviations in Neptune's motion to detect the effect of Planet X. And since Planet X was far from Uranus, the perturbations it caused in Uranus' motion were minute compared to those induced by Neptune. The theoretical part of the task would be far more difficult than that confronted by Adams and Leverrier.

Lowell also recognized that the observational problem facing him was much more difficult. Neptune was bright in comparison to the predicted Planet X. It took a few minutes to find Neptune; it would take many years to discover Pluto. Lowell also realized that the procedure he used for examining photographic plates was no way to conduct his investigation. Up until then, he had compared two plates at a time by superimposing them and searching for suspicious objects with a magnifying glass. In 1911 Lowell ordered a blink comparator for the observatory. This machine allows the examination of two plates of the same region of sky by alternating them. Any moving object — asteroid, comet, or planet — reveals itself by traversing the field while the stars remain stationary.



One of the pair of photos used to discover Pluto. Pluto lies at the tip of the arrow. Lowell Observatory photo.

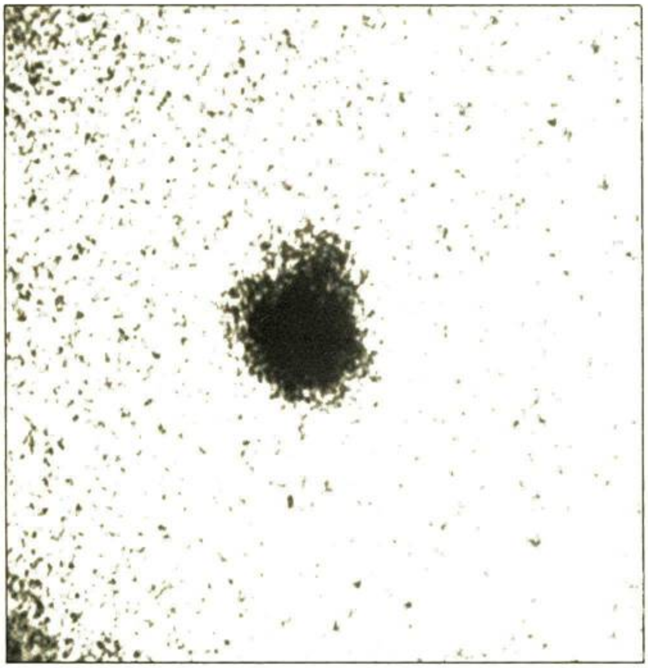
Having acknowledged the difficulty of the problem before him, Lowell plunged into the exhausting and tedious calculations necessary to predict the hypothetical planet's position. He hired several people to help, and together they performed thousands of calculations. After completing his preliminary investigation, Lowell ordered a second photographic search to begin in March 1911 — a search that would, in a sense, capture the world he was seeking.

Even as plates were being exposed at his observatory in Flagstaff, Arizona, Lowell and his staff continued their calculations. Lowell sent telegrams to Arizona, updating these calculations. He was not only hoping for an early victory, he was expecting one. Never before had anyone conducted such a massive search, but the continuing lack of success began to drain Lowell of his earlier enthusiasm.

Yet on March 19, 1915, and again on April 7, 1915, a faint object was recorded on the photographic plates. Unlike the stars, it moved; it lay in the ecliptic, buried in the Milky Way between Taurus and Gemini. This object was far, far beyond Neptune, yet no one noticed it.

Lowell died on November 12, 1916, without finding Planet X. He left more than one million dollars for the observatory, but his widow, Constance Lowell, challenged this arrangement. A bitter legal battle ensued and lasted more than ten years, during which time Lowell Observatory could not afford to continue the search. This delay nearly handed a new world to Lowell's chief competitor.

In 1919 Henry Pickering published revised elements



The discovery photo of Pluto's moon, Charon, taken in 1978. Charon is the elongated "bump" on the top of Pluto. United States Naval Observatory photo.

for his Planet O — elements that took into account Planet O's effect not only on Uranus but also on Neptune. He predicted the planet would lie near the border between Taurus and Gemini and asked astronomers to search for it. In late December 1919, astronomers at Mount Wilson turned one of the observatory's telescopes toward the region; on four different photographic plates a faint, trans-Neptunian object was recorded moving slowly along the ecliptic. But once again, no one noticed it at the time.

His failure to find Planet O convinced Pickering it did not exist. In 1928, he proposed a totally new orbit for Planet O, an orbit that resembled Pluto's in a very prescient way: at perihelion, Planet O was closer to the Sun than Neptune.

In 1929, Lowell Observatory resumed its search for Planet X with full vigor. Early that year, a 13-inch lens, bought by the observatory from the estate of the Reverend Joel Metcalf, arrived at Flagstaff, as did a young amateur astronomer from Kansas named Clyde Tombaugh. Tombaugh was only twenty-two years old when he came to Lowell Observatory and had no formal training in astronomy. But Tombaugh's inexperience was a plus: the financially strapped observatory would not have to pay him as much as an older, professional astronomer.

In April Tombaugh began exposing plates and on the 11th, while searching Gemini, he unknowingly recorded the image of a tiny world circling the Sun beyond the planet Neptune. For the third time, Pluto went unnoticed.

During the summer rainy season, Tombaugh stopped exposing plates. He now had a stack of them to blink, but as he started to do so, he became filled with despair. He found that if one plate went to fainter magnitudes than the other, he could not blink them effectively. Worse yet, hordes of asteroids whizzed across the plates; how could he tell them from Planet X?

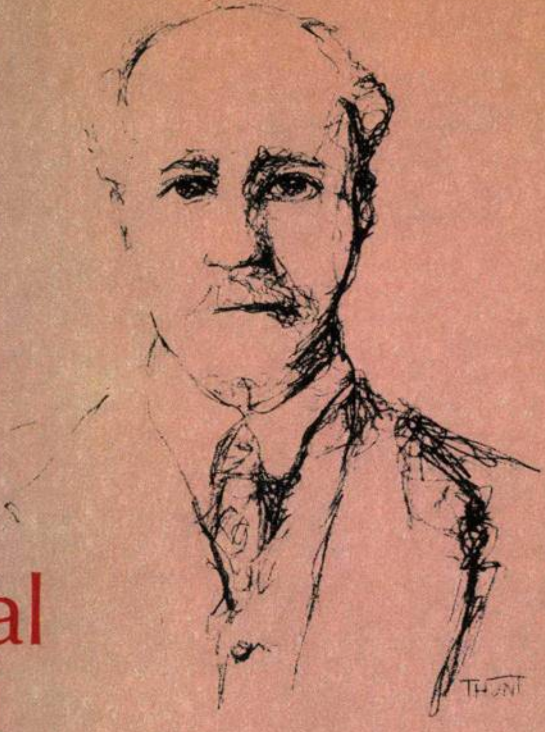
Tombaugh spent the summer thinking about his difficulties. It was clear that in the future he must expose each plate to the same magnitude. More importantly, he had to devise a method to distinguish asteroids from more distant objects. Tombaugh found that if he took a plate of the region of sky directly opposite the Sun, the movement of Earth about the Sun would make the motion of a planetary body inversely proportional to its distance. Nearby asteroids would move across the plates much faster than the planet Tombaugh was seeking.

Toward the end of the summer, Tombaugh implemented his new plan. He started in the constellation Aquarius and worked his way into Pisces and Aries. By November he was taking photographs of Taurus, moving closer and closer to the constellation Gemini. In January, Tombaugh pointed the telescope at the star Delta Geminorum and took three plates of the region: one on the 21st, the next on the 23rd, and the last on the 29th.

It was on February 18, 1930, that Tombaugh looked at the three Gemini plates. The one from January 21 was not good — seeing had been poor that night — so Tombaugh blinked the January 23 and 29 plates. He began blinking them in the morning and by mid-afternoon had completed about one-quarter of the plates. At 4:00 p.m. he moved into a new region on the plates. Suddenly, jumping back and forth amongst the fixed stars, there appeared a most puzzling object. Tombaugh noticed the shift of the object was small, too small to be a nearby asteroid. Could it be a plate defect? With increasing excitement, he reached for the January 21 plate. The mysterious object was there as well, and in exactly the right place.

At 4:45, Tombaugh informed his superiors of the discovery. That night they sought to observe it, but the sky was cloudy. The next night was clear and the astronomers located the object, but the new-found world did not show a disk, which disappointed and worried them. They also noted that it was much fainter than Lowell had predicted. The astronomers observed the object over the next several weeks, tracking it as it slowly moved against the stars.

Late on March 12, the astronomers sent a telegram to Harvard College Observatory announcing the discovery. Following this announcement, the public besieged Lowell Observatory for news about the object. A great debate developed over the object's name. Lowell's widow, Constance, who had delayed the search through her lawsuit, first wanted "Zeus" and later suggested "Percival," "Lowell," and finally "Constance." Under-



Percival Lowell

A Controversial Pioneer

Percival Lowell, a well-heeled writer, traveler, and astronomer, was born to a prominent Boston family on March 13, 1855. His relatives included younger brother Abbott Lawrence, president of Harvard University for twenty-four years, and sister Amy, a famous avant-garde poet. In addition to launching the search that eventually found Pluto, Lowell made other significant contributions to astronomical knowledge.

Despite a lifelong interest in astronomy, Lowell did not actively pursue this interest as a young man. After graduating with honors from Harvard in 1876, he spent most of the ensuing seven years as a businessman in his grandfather's office. For the next ten years, Lowell traveled extensively and wrote several books and numerous articles about his experiences.

It was not until 1893 that astronomy became Lowell's real passion. In that year he learned that the famous Italian astronomer Giovanni Schiaparelli was losing his eyesight. Schiaparelli had detected narrow lines he called "canali" on the surface of Mars during the favorable opposition of 1877. Although "canali" means "channels" in Italian, it was mistranslated into English as "canals" — a word suggesting waterways constructed by intelligent beings. Upon hearing of Schiaparelli's condition, Lowell decided to take up the Italian's studies of the planets.

He established an observatory to study Mars with the assistance of Andrew Douglass and William Pickering, two Harvard planetary astronomers who had backgrounds in Mars observing. Lowell Observatory opened on June 1, 1894 at Flagstaff in the high desert of Arizona.

Soon after the construction of the observatory, Lowell began to promote controversial ideas about Mars and its "inhabitants," ideas that he advocated until his death in 1916. During his lifetime, Lowell was best known for these theories. He wrote three books on Mars, drafted numerous articles, and presented hundreds of lectures on the subject.

It's difficult to fully understand Percival Lowell's scientific theories without considering his political beliefs: he was a fervent pacifist. Lowell looked to Mars as a mirror of the better side of ourselves. Here, according to Lowell, was a dying planet that had lost most of its water; the two polar caps held all the water that remained. In order to distribute this scarce resource to the equatorial regions, the Martians had built long canals from the poles to the equator. Such a huge network required that all the inhabitants of Mars cooperate with one another, since war initiated by one nation would spell the end for all. As Lowell said, "Isolated communities cannot there be sufficient unto themselves; they must combine to solidarity or perish." Mars, named after the god of war, was actually a world of peace.

Lowell spent some fifteen years studying Mars, both visually and photographically. He was convinced that the canals were real and he eventually observed over 500 of them, far more than Schiaparelli ever did. He made careful maps of their locations, which included "oases" where some of the canals met. Lowell also studied the changes in surface markings that took place as the seasons progressed, changes he attributed to Martian agriculture.

Although the Lowellian theories excited the public and inspired science fiction writers, they outraged professional astronomers. Perhaps in an effort to attain credibility among other astronomers, Lowell began to turn his attention to a planet yet to be discovered. Although his Martian theories were well known to everyone, his search for "Planet X" was carried on secretly. Most astronomers knew nothing of it until Pluto's discovery in February 1930.

Lowell's brother, Abbott Lawrence, wrote that the failure to find Planet X "was the sharpest disappointment of [Percival Lowell's] life." Lowell's lifelong friend, George Agassiz, said it "virtually killed him."

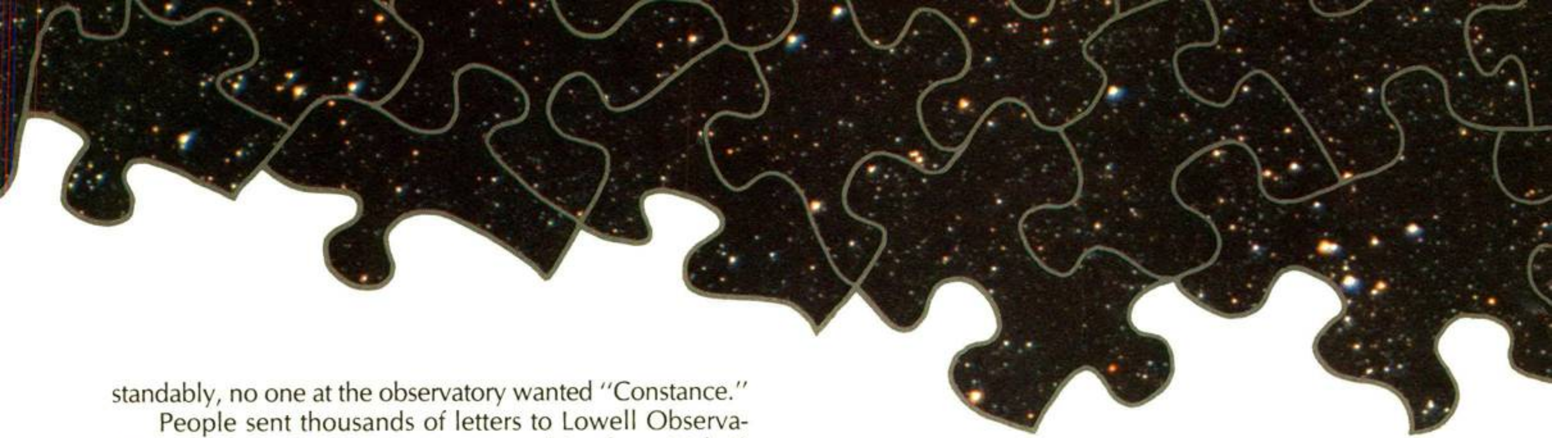
Percival Lowell was a defeated man: his Martian theories were no longer accepted, his observatory was ostracized, and his planet still awaited discovery. During the summer of 1916, Lowell sent one of his last telegrams to Flagstaff: "Please see that wild flowers on [Mars] are never picked. Put up notices." In October, he returned to Flagstaff to study the moons of Jupiter. On November 12, Percival Lowell suffered a stroke and died at his observatory.

It would be unfair to remember Percival Lowell simply as a man with bizarre beliefs about Mars. He initiated and was directly involved in the search that led to the discovery of Pluto. Even more importantly, under his direction Lowell Observatory launched many important projects that would later bear fruit.

Perhaps the most significant of these were the spectrographic studies of "spiral nebulae" carried out by Vesto Melvin Slipher, Lowell's chief assistant. By determining the radial velocity of these objects, Slipher was able to show that most were receding from the Milky Way at speeds then considered incredible. Edwin Hubble used these specific observations to show that the universe was actually expanding — an idea that now forms the cornerstone of modern cosmology.

The best way to remember this early American astronomer might be for his perseverance. This is the quality that shines through both his successes and failures. A fitting tribute for his contribution to the search for Pluto is the symbol for that planet. The combination of the letters P and L symbolize the first two letters of Pluto's name, as well as the initials of the man who searched for that planet so long in vain — Percival Lowell.

— Ken Croswell



standably, no one at the observatory wanted "Constance."

People sent thousands of letters to Lowell Observatory, each suggesting a name — everything from "Atlas" to "Zymal." "Zymal," the proposer explained, was "the last word in the dictionary" for "the last word in planets."

Fortunately, other names prevailed. The three most popular were "Minerva," "Cronus," and "Pluto." Minerva was the goddess of wisdom, a fitting name for a planet predicted in advance of its discovery. But it was also the name of an asteroid, and so it was unacceptable. Cronus was out because the American astronomer Thomas Jefferson Jackson See had used it for one of his predicted planets. This left Pluto, the god of the underworld, a god in perpetual darkness.

Pluto's orbit proved to be similar to the orbit of Lowell's Planet X and Pickering's Planet O, lying within six degrees of the predicted positions. Pickering noted the similarity between Pluto and Planet O but gave Lowell credit for having conducted the search that led to Pluto's discovery.

But there was a major problem with Pluto: both Lowell and Pickering had greatly overestimated the planet's mass. Since Pluto was so faint, astronomers concluded its mass had to be less than Earth's. Yet Pickering had assigned Planet O a mass twice that of Earth, and Lowell's Planet X had a mass 6.7 times Earth's.

Yale mathematician Ernest Brown, after reviewing Lowell's analysis, believed Pluto's discovery was an accident. He claimed that such a tiny object would hardly affect either Uranus or Neptune. But the controversy over the validity of the predictions continued, fueled by our ignorance of Pluto's mass.

The Discovery of Charon

The easiest way to determine Pluto's mass requires Pluto to have a moon. For a given separation between a planet and its satellite, the satellite must revolve faster the more massive the planet is. This is because a more massive planet has a greater gravitational pull and the satellite must then move faster to keep from falling into the planet. The problem with Pluto was it had no satellite . . . or so we all thought.

In an attempt to refine Pluto's orbit, James Christy of the U.S. Naval Observatory examined photographs of the planet taken in April and May 1978. On June 22, 1978, he noticed Pluto's image was elongated rather than round.

Such images can appear when photographic plates are defective or when atmospheric seeing is bad. But Christy also found other plates that showed Pluto to be elongated. Assuming the "bump" on Pluto to be a satellite, Robert Harrington, also at the Naval Observatory, calculated the object's orbit. He found the period of the moon to be equal to Pluto's rotation period, about 6.4 days.

Christy proposed the name "Charon" for the moon. Charon would be a fitting companion for Pluto, god of the underworld, since he was the ferryman who carried souls across the river Styx.

Although Christy discovered Charon in 1978, the satellite was not officially recognized then. No one could produce enough images clearly separating the two bodies to determine Charon's orbit reliably, so astronomers could not formally acknowledge its existence. Brian Marsden of the Harvard-Smithsonian Center for Astrophysics even proposed that the elongation might be a giant mountain on Pluto, though most planetary astronomers rejected the idea. Then, in 1985, Pluto and Charon began to eclipse each other, convincing even the skeptics of Charon's existence.

Charon is difficult to separate from Pluto not only because Pluto is so far from Earth but also because Charon is so close to Pluto. The two are only 19,400 kilometers apart. In contrast, the Earth and Moon are separated by 384,000 kilometers. Despite its closeness, Charon takes a leisurely six days to circle Pluto. A satellite that close to Earth would whip around once every seven hours.

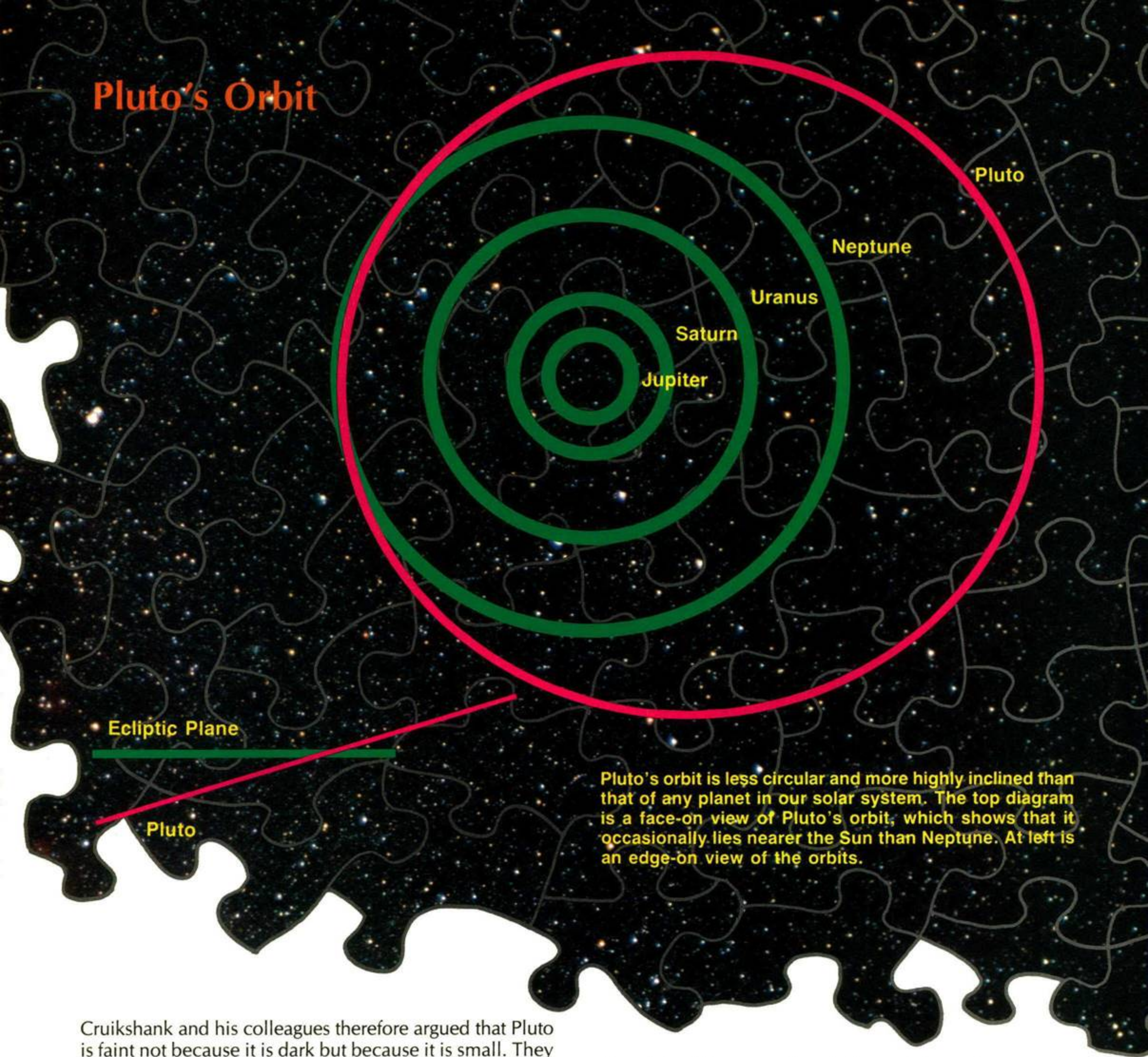
Charon takes so long to circle Pluto because it doesn't have to go any faster; Pluto has so little mass that the gravitational pull on its companion is not very strong. From the Pluto-Charon separation and the satellite's period, astronomers have calculated Pluto's mass to be about .0021 of the Earth's mass, a far cry from Lowell's Planet X (6.7 times the Earth's mass) or Pickering's Planet O (2.0 Earth masses).

Pluto is many times fainter than Planet X and less than 1/3,000 as massive. For all practical purposes, it has no effect on either Uranus or Neptune. The Earth, in fact, exerts a much stronger gravitational force on Neptune than Pluto ever does. The discovery of such a faint, distant object is a testimony to the quality of the search rather than the validity of the calculations. The thoroughness of the hunt compensated for the elusiveness of the prey.

Although Pluto's mass is far less than Lowell's prediction, the planet is also much smaller than previously determined values. Based on Pluto's faintness, astronomers first estimated it had a mass less than that of the Earth. During the late 1960s and early 1970s, two different investigations placed Pluto's mass between .10 and .20 of the Earth's mass. This value came from the analysis of deviations in Neptune's orbit. Astronomers calculated the mass Pluto must have in order to perturb Neptune's orbit by the observed amount.

In 1976, Dale Cruikshank, Carl Pilcher, and David Morrison of the University of Hawaii discovered methane ice on Pluto. All along, astronomers had been assuming Pluto's surface was dark in order to explain its faintness. But methane ice reflects a large percentage of sunlight.

Pluto's Orbit



Pluto's orbit is less circular and more highly inclined than that of any planet in our solar system. The top diagram is a face-on view of Pluto's orbit, which shows that it occasionally lies nearer the Sun than Neptune. At left is an edge-on view of the orbits.

Cruikshank and his colleagues therefore argued that Pluto is faint not because it is dark but because it is small. They estimated Pluto's mass to be a mere .004 Earth masses — some forty times smaller than the accepted value.

The discovery of Charon and the subsequent determination of Pluto's mass eliminated Pluto as the culprit responsible for the deviations in Neptune's orbit. It does not, however, remove those deviations; they still exist.

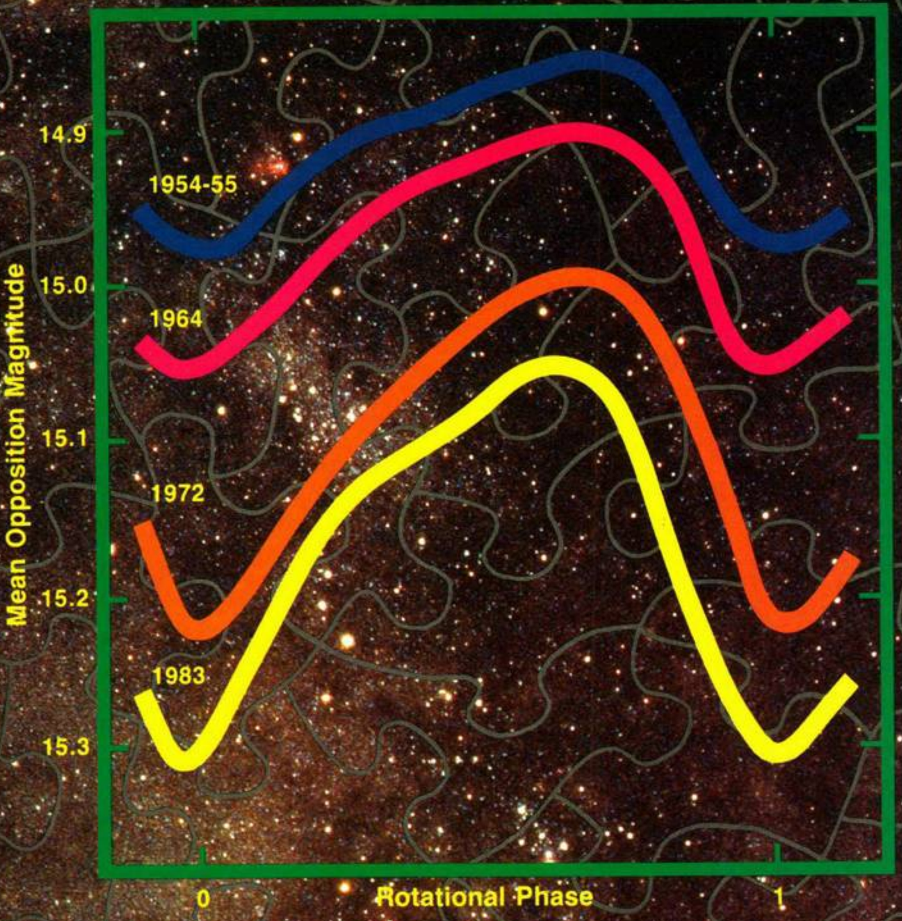
Pluto

Nearly sixty years after its discovery, Pluto remains a mystery on the edge of the solar system. The planet takes 247.7 years to orbit the Sun, completing two orbits in the time it takes Neptune to make three. Pluto's average distance from the Sun is 39.4 astronomical units, considerably greater than Neptune's distance of 30 AU.

But Pluto's average distance from the Sun is hardly a good guide to its present location. The planet's elliptical orbit is so eccentric that it ventures as far as 49.3 AU from the Sun at aphelion. Right now, however, Pluto is on the opposite side of its orbit, racing toward perihelion in 1989, when it will be a mere 29.6 AU from the Sun — inside the orbit of Neptune. Pluto left trans-Neptunian space in 1979 and will return to it in 1999. Despite its strange orbit, Pluto will never collide with Neptune: Pluto is always several astronomical units north of Neptune when their orbits cross.

Pluto's elliptical orbit is more eccentric than that of any planet in the solar system. (Eccentricity is a measure of how flattened an ellipse is. A circle has an eccentricity of 0 and a parabola has an eccentricity of 1.) With an orbital eccentricity of .25, it tops the two greatest planetary orbital eccentricities, those of Mercury (.21) and Mars (.09). Pluto's orbit is inclined 17° to the plane of the ecliptic, more than double that of the greatest planetary orbital inclination (7°, courtesy again of Mercury).

As Pluto revolves about the Sun, it spins slowly on its axis. In the 1950s, Merle Walker and Robert Hardie measured the brightness of Pluto on different nights from Mount Wilson and Lowell Observatories. They discovered that Pluto varies in brightness every 6.4 days, which



The Dimming of Pluto

Due to bright and dark regions on its surface, Pluto varies in brightness as it rotates. However, the planet is getting dimmer as it approaches perihelion. Its light curve is now .3 magnitudes below that recorded in the 1950s.

indicates that it rotates more slowly than any of the outer planets. Further work has refined the length of Pluto's day to 6 days, 9 hours, and 18 minutes.

Although Charon revolves about Pluto with the same period as Pluto's rotation, Charon is too faint to account for Pluto's varying brightness. The brightness fluctuation means that Pluto's surface is not uniform. There must be bright (icy?) as well as dark (rocky?) areas on Pluto. When the more reflective parts turn toward us, Pluto brightens; when the darker areas face us, Pluto dims.

Ever since its discovery, Pluto has been drawing closer and closer to the Sun and thus to the Earth. Pluto therefore appears brighter every year. In 1930, Pluto's photographic (blue) magnitude was 15.6; today Pluto shines at photographic magnitude 14.5 and its V (yellow) magnitude is 13.7.

But in the 1960s astronomers began to suspect something was wrong; in the 1970s they confirmed these suspicions. Although Pluto has brightened, it has not brightened as much as expected. In order to compare Pluto's brightness at two different dates — which implies two different distances — astronomers convert the observed brightness to a standard scale: how bright it would be at its average distance from the Sun. The resulting value is called the mean opposition magnitude.

In the 1950s, Walker and Hardie found that Pluto's mean opposition magnitude at visual wavelengths was 14.9. By the 1960s it dropped to 15.0 and fell to 15.1 in the 1970s. The latest reports indicate the mean opposition magnitude is now 15.2. Pluto is darkening as it nears perihelion. But why?

One possibility is that as Pluto approaches the warmth of the Sun some of its bright ice is melting, exposing darker rock beneath. A competing theory involves Pluto's large obliquity. A planet's obliquity is the angle its equator makes with the plane of the solar system. Most planets have small obliquities; Earth's, for example, is only 23.5°. Pluto, though, has an obliquity of about 118°, which means it lies on its side and presents different views of itself as it orbits the Sun. When Pluto was discovered, its pole pointed toward us; now, one-fourth of a revolution later, Pluto's equator faces us. Perhaps the apparent darkening of Pluto is the result of this change in our perspective. Pluto's equatorial regions may be darker than its polar areas, which may have polar caps.

Although Charon has revealed Pluto's mass to us, another key parameter — Pluto's diameter — still eludes us. Dutch-American astronomer Gerard Kuiper tried to estimate Pluto's diameter in 1950 using the 200-inch telescope on Palomar Mountain. His estimate of 5,900 kilometers remained the accepted one for twenty-five years. In April 1965, Pluto passed close to a 15th-magnitude star but did not occult it. This near miss indicates the planet's diameter must be less than 6,800 kilometers.

But Pluto is also a faint world. If it really has a diameter as large as 5,900 kilometers, it must be quite dark. Otherwise it would reflect too much light back to Earth. The percentage of light a planet reflects is called its albedo. A dark substance, such as coal, has a low albedo, and a bright substance, such as snow, has a high albedo. A diameter of 5,900 kilometers implies an albedo of only 13 percent.

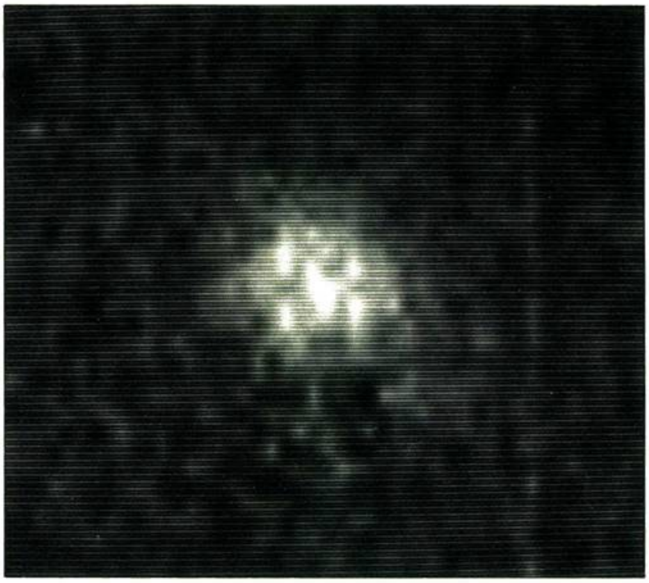
The 1976 discovery of methane ice on Pluto means Pluto's surface must reflect more sunlight. A more reasonable albedo is around 50 percent, which would cut Pluto's diameter to a mere 3,050 kilometers — smaller than our Moon (3,476 kilometers).

Astronomers want to know Pluto's mass and diameter not only because these are interesting quantities but because they will tell us Pluto's density. Density is simply mass divided by volume. A planet's density gives us a good clue to its composition. In the past, astronomers drastically overestimated Pluto's mass, so they also overestimated its density. Some combinations of mass and diameter produced absurd results. Densities of 40 grams per cubic centimeter (g/cc) implied a planet far denser than lead. Even the values accepted for Pluto's mass and diameter in the 1970s led to densities of 6 g/cc.

In retrospect, it's hard to understand how anyone could have believed this. Pluto is a member of the outer solar system where ice is common, and ice is light. The three densest planets — Mercury (5.43 g/cc), Venus (5.24 g/cc), and Earth (5.52 g/cc) — all reside in the inner solar system where the primitive solar nebula was hot and did not allow ices to condense. Since Pluto lies far from the Sun, it should be a low-density object.

Even today, however, we don't know precisely what Pluto's density is. We do know Pluto's mass and its apparent brightness. What we don't know are Pluto's albedo, density, and diameter. But if we determine only one of these three unknown quantities, we can automatically determine the other two as well. For example, if we can measure Pluto's diameter, we will know Pluto's density (since we know its mass) and albedo (since we know its apparent brightness).

Actually, even though we can't pin down these quantities precisely, they can still give us information about Pluto. First consider the albedo: it can't be greater than 100 percent. If Pluto has an albedo of 100 percent, then its diameter is 2,160 kilometers and its density is 2.3 g/cc. This is the smallest and densest Pluto can possibly be.



This image has been computer processed to show Charon by itself; the image of Pluto was removed electronically. The two objects orbit so close to each other that any photograph of one also captures the other. University of Arizona photograph.

But we can do even better. It's nearly impossible for Pluto's surface to be 100 percent reflective. Even good old-fashioned Earth snow has an albedo of only about 70 percent. If Pluto has an albedo of 70 percent then its diameter is equal to 2,580 kilometers and its density is 1.4 g/cc.

Now let's look at the second unknown, Pluto's density. Ideally, we would want to measure Pluto's density and from that determine what it is made of. But we don't know the density, so let's reverse the logic. What do we expect Pluto to be made of?

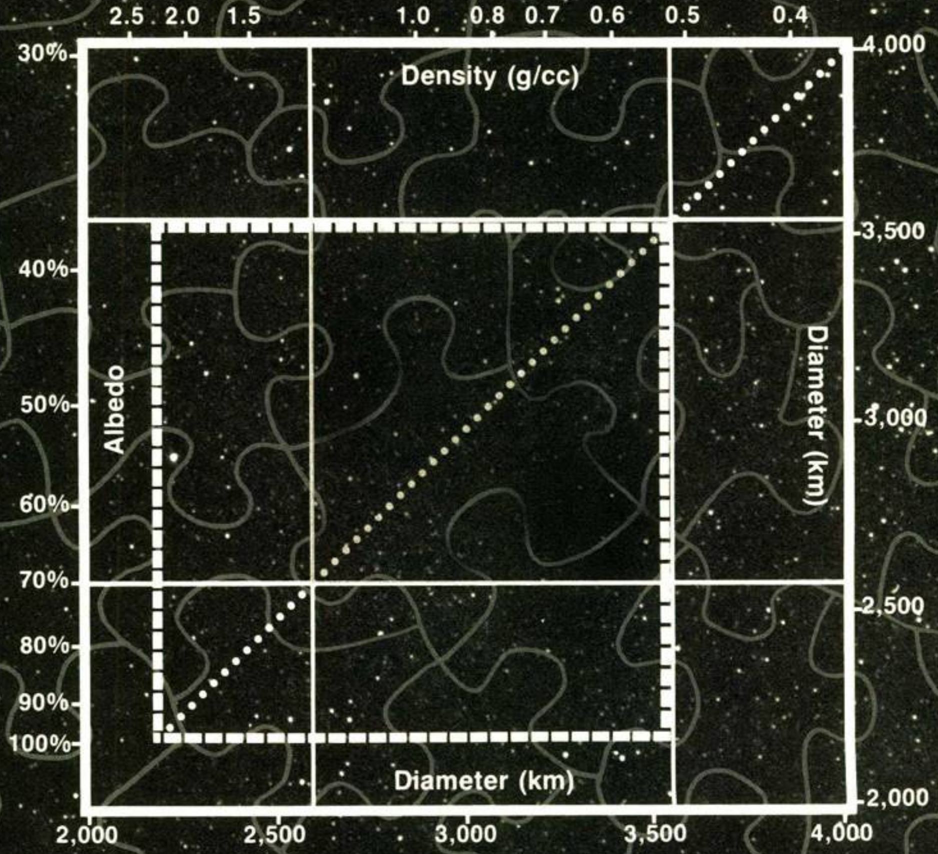
There are three plausible candidates. First, there's rock. Rock is a fairly dense substance, and we've already inferred that Pluto's density is less than 1.4 g/cc. This implies Pluto can't have much rock.

The second candidate is water ice, which probably makes up much of Pluto's mass. Liquid water has a density of 1.00 g/cc; since water ice floats in liquid water, ice has a somewhat lower density. But Pluto's weight squeezes this ice, increasing its density to 1.14 g/cc. If Pluto has a density of 1.14 g/cc, its diameter is 2,730 kilometers and its albedo is 63 percent, both reasonable values.

But let's go to the extreme. The lightest thing Pluto could be made of is methane ice, which has a density of only .53 g/cc. If Pluto's density is this low, the diameter would be 3,530 kilometers and the albedo 38 percent. Therefore, Pluto's diameter must be less than 3,530 kilometers and its albedo is greater than 38 percent.

Constraints on Possible Plutos

Our knowledge of Pluto's mass and apparent brightness places limits on Pluto's diameter, albedo, and density. In principle, Pluto could lie anywhere on the diagonal line. Since its density must be greater than methane ice (0.53 g/cc) and its albedo less than 100 percent, possible Pluto's are confined to that part of the diagonal line within the dashed-line area. But since Pluto's albedo is probably less than 70 percent, we can confine Pluto to the shaded region of the diagram.



Now let's pull all this together. We've just determined realistic ranges for each of the three unknowns. Pluto's diameter must be between 2,580 and 3,530 kilometers, its density between .53 g/cc and 1.4 g/cc, and its albedo between 38 and 70 percent. This argument is shown graphically in the diagram above.

Even though we don't yet know Pluto's density, the above ranges give us a rough idea of the planet's interior structure. We expect Pluto's core to be composed of rock, but this component is probably quite small; if it were a larger component of the core, the overall density would be too high. Surrounding the rocky core is a mantle of water ice and enveloping that is a crust of methane ice. Scientists suspect that the water-ice mantle makes up most of Pluto's mass.

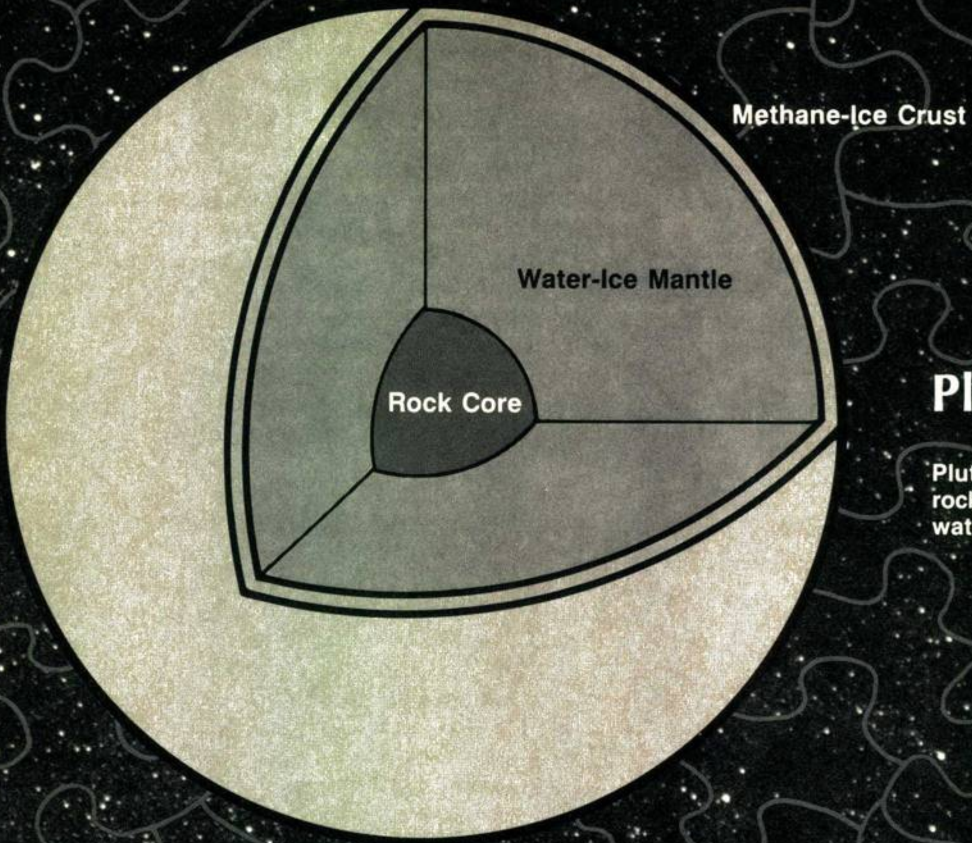
Now that we've considered the interior of Pluto, let's voyage to the surface. What would we find if we could walk on Pluto? First, it's cold: the temperature hovers between 40 and 60 degrees Kelvin (−390° to −350° Fahrenheit), being warmest when Pluto is near perihelion. (For comparison, Uranus and Neptune are around 58 K). Second, the surface has methane ice with possible outcroppings of rock. Craters should be abundant and small mountains could exist as well.

Since spectroscopic evidence suggests Pluto's surface contains methane ice, some of it may sublime to form a tenuous atmosphere. Unfortunately, it's difficult to differentiate methane gas and methane ice from Earth, so astronomers are currently debating whether the gas has actually been detected. The atmosphere is probably thickest when Pluto is closest to the Sun, as it is now, since Pluto is then at its warmest.

But Pluto may have more than methane in its atmosphere. In fact, methane could turn out to be only a minor component. If Pluto's atmosphere contains another gas, that gas must be heavy, otherwise Pluto's weak gravity couldn't hold on to it. It also must be difficult to observe, for no one has yet detected any gas on Pluto besides methane. One possibility is argon, which is a heavy and chemically inert gas; another candidate is neon. Nitrogen is also attractive because Saturn's moon Titan has a lot of it.

Charon

What about Pluto's moon? Although it has told us much about Pluto, Charon remains even more mysterious than the world it orbits.



Pluto's Interior

Pluto's interior probably consists of rock, water ice, and methane ice, with water ice the dominant component.

Charon lies 19,400 kilometers from Pluto and revolves about it in a circular orbit once every 6 days, 9 hours, and 18 minutes. Since this is exactly Pluto's rotation period, Charon continually hovers over the same region of Pluto. Charon keeps its same side to Pluto, and Pluto keeps its same side to Charon. As our Moon circles the Earth, it also keeps its same face to us, but the Earth does not keep its same side to the Moon.

That Charon has forced Pluto to stare at it means Charon's mass must be greater than 5 percent of Pluto's. Astronomers usually assume Charon's mass is about 10 percent of Pluto's, but this is only an educated guess. Still, even at 5 percent the mass of Pluto, Charon is the most massive satellite relative to its primary in the solar system. The previous record-holder was our Moon, whose mass is about 1 percent of Earth's.

The only other solid piece of information we have about Charon came when Pluto passed a star in April 1980. Observing the event from South Africa, astronomer Alistair Walker noted that although Pluto missed the star, Charon eclipsed it for 50 seconds. This duration implies that Charon's diameter is at least 1,200 kilometers.

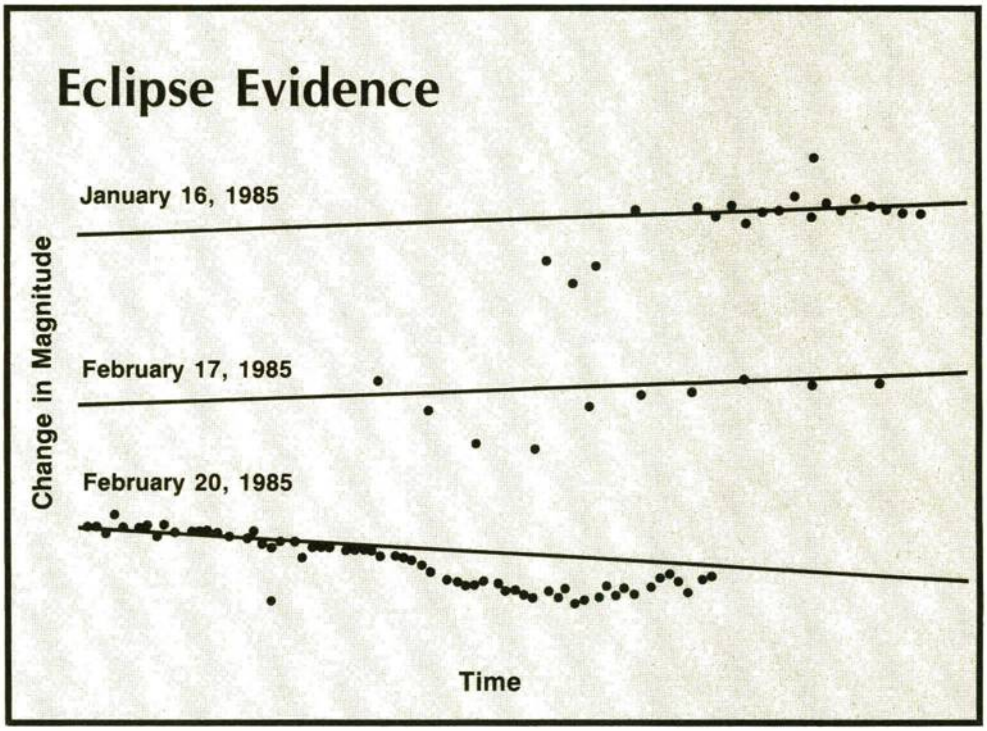
All else about Charon remains speculation. We presume it is much like Pluto: its surface bears methane ice, it has a low density, and it is very cold.

The Origin of Pluto

For many years the only thing astronomers knew about Pluto was its odd orbit and low brightness. The orbit is more eccentric and far more inclined than the orbit of any planet in the solar system.

But two other distant objects have equally peculiar orbits: Triton and Nereid, the two known moons of Neptune. Triton is one of the largest satellites in the solar system, yet it circles Neptune in a retrograde orbit. Furthermore, its orbit is inclined 21° to Neptune's equator. The other satellite, Nereid, revolves around Neptune in an orbit with an eccentricity of .76 — by far the largest orbital eccentricity of any satellite.

Could Pluto be an escaped moon of Neptune? And if so, did the event that ejected Pluto from Neptune also disturb the orbits of Neptune's other satellites? Astronomer Raymond Lyttleton thought so. In 1936 he proposed that while a satellite of Neptune, Pluto ventured so close to Triton that it was thrown out of the Neptunian system. Triton remained bound to the planet but was forced into its strange orbit.



Pluto and Charon began eclipsing each other in early 1985. The solid lines indicate the brightness expected for the system in the absence of eclipses; the slope of these lines varies because of Pluto's rotation. The dots represent actual observations on three nights. Since the dots dip below the solid lines, they record evidence of the eclipses.

At the time Lyttleton did not know about Nereid, which was not discovered until 1949 by Gerard Kuiper. In 1956 Kuiper offered a different scheme for the origin of Pluto: he thought it escaped from Neptune as the planets were just forming.

In 1979, Robert Harrington and Thomas van Flandern of the U.S. Naval Observatory proposed the most radical possibility. They suggested that a planet passed near Neptune, took Pluto from it, and disturbed the orbits of Triton and Nereid. Computer simulations indicated this planet had to have a mass two to five times that of the Earth. According to Harrington and van Flandern, it still orbits the Sun but in a very eccentric orbit.

Few astronomers take this last suggestion seriously, although it is unlikely that Pluto could have been ejected into its present orbit without the help of an intruding planet. While some astronomers believe Pluto is an escaped moon of Neptune, the majority think Pluto is a planetesimal — a leftover building block from the formation of the planets. According to this theory Pluto has always held its present orbit but, unlike the other planetesimals, it never collided with a major planet.

Still, Pluto and Triton are very similar. Both contain methane ice, both probably have methane atmospheres, and both may be the same size. Triton, according to these astronomers, was also a planetesimal, but Neptune captured it and made it a satellite. Thus, Pluto is what Triton could have been, had Neptune not interfered.

The Eclipses

Every 124 years, which is half Pluto's year, we view the equatorial plane of Pluto edge-on. During these periods, Charon eclipses Pluto and Pluto eclipses Charon. By a stroke of good luck, such an eclipse season began in 1985 and will last for several years. Scientists are now monitoring the eclipses to learn as much about these worlds as possible.

Although a spacecraft mission would be the best way to learn more about Pluto, the eclipse season is the next best thing to being there. Once completed, much of the speculation presented here will be replaced with solid knowledge.

The duration of the eclipses will give us the diameters of both Pluto and Charon and these will allow us to calculate their densities. Furthermore, as Charon eclipses different parts of Pluto, scientists can determine the albedo of various regions on Pluto. From this information we will actually be able to map Pluto — albeit crudely.

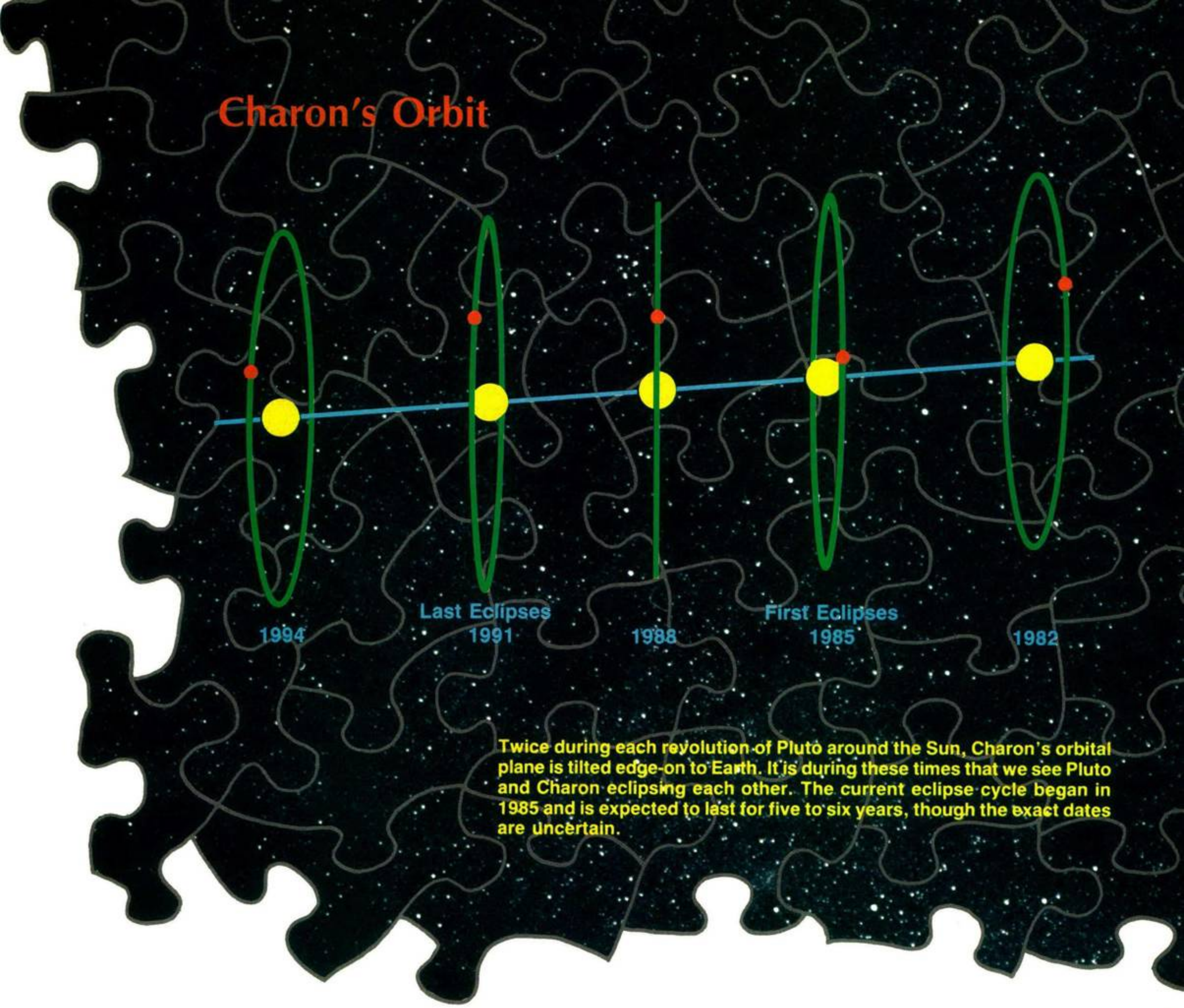
What if Charon had not been discovered? Would someone have noticed the periodic dips in Pluto's light in the 1980s? It's possible no one would have systematically observed it. Charon is a major reason astronomers are interested in Pluto again, for it still has much to teach us about Pluto.

A Spacecraft to Pluto?

Even after the current eclipse season is over, much will remain unknown about Pluto and its satellite. We have stretched our observations and our logic to the limit and still we know less about these worlds than about any of the planets of the solar system.

The Hubble Space Telescope will be able to clearly

Charon's Orbit



Twice during each revolution of Pluto around the Sun, Charon's orbital plane is tilted edge-on to Earth. It is during these times that we see Pluto and Charon eclipsing each other. The current eclipse cycle began in 1985 and is expected to last for five to six years, though the exact dates are uncertain.

separate Pluto from Charon, allowing us to precisely determine Charon's orbit. But even the superb resolution of the Space Telescope will not be able to resolve features smaller than half of Pluto's diameter.

If we are ever to discern the true natures of these alien places, we must send a spacecraft past them to see what they look like, to take precise measurements, and to determine their actual compositions. But to have a reasonable flight time, we must act within the next few decades. Pluto comes closest to the Sun in 1989, bringing it a billion miles closer to us than usual.

Unfortunately, U.S. spacecraft flybys depend less on celestial mechanics than on Washington politics. In the early 1970s scientists proposed sending a spacecraft past Jupiter, Saturn, and on to Pluto. It would have arrived at Pluto in 1985 or 1986, but the politicians rejected it.

What of the future? In order to send a spacecraft to Pluto, we need Jupiter to provide a gravitational assist. Jupiter cuts a forty-year journey down to a mere ten or fifteen years. Launch opportunites occur when Jupiter positions itself correctly, which is once every twelve years. The next such window occurs in the late 1980s — too soon for us to take advantage of it. The next chance will come at the beginning of the twenty-first century; let's hope we will make use of it then.

Is Pluto a Planet?

No. At least it's not a planet like any of the other known planets. It fooled us for a while, but now that we know its mass we must recognize that, if there is a ninth planet in our solar system, it has yet to be found.

All of this does not sit well with Pluto's discoverer. In arguing for Pluto's planethood, Clyde Tombaugh has compared its orbital eccentricity and inclination to that of Mercury. Although Pluto's orbital eccentricity of .25 is similar to Mercury's (.21), its orbital inclination of 17° is more than twice as great as Mercury's (7°).

But Pluto's odd orbit is not the point. It's Pluto's mass that separates it from the other planets. The two least massive planets in the solar system are Mars and Mercury. Mars has a mass one-ninth that of Earth's, Mercury's mass is one-half of that. Pluto, on the other hand, has a mass about $\frac{1}{500}$ of Earth's. If Pluto was even close to the size of the other planets, Tombaugh would never have found it. If Pluto were as massive as a proper planet, Lowell

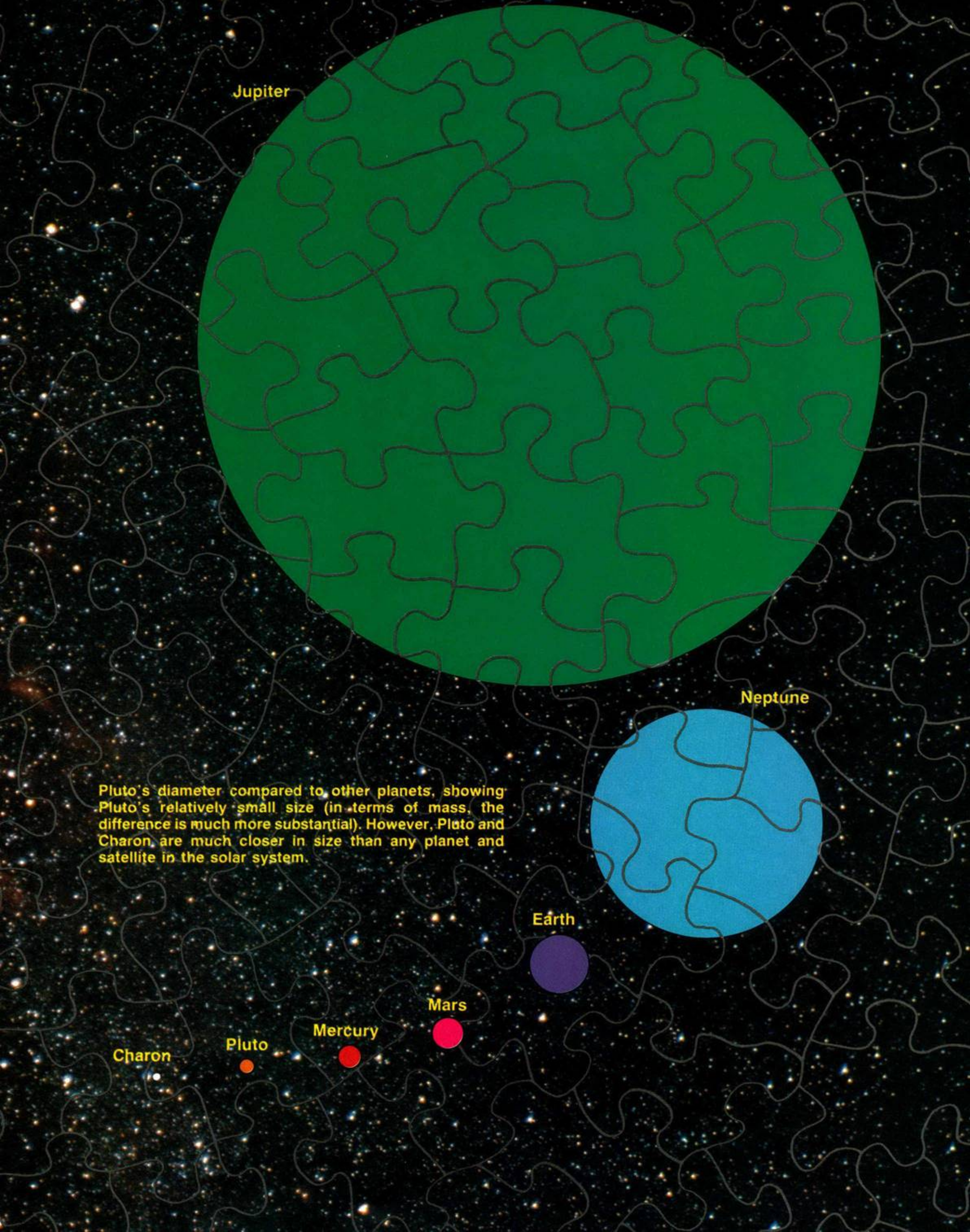
Physical and Orbital Characteristics of Pluto and Charon

Pluto

Average Distance from Sun	39.44 AU
Diameter	2,580 to 3,530 kilometers
Year	247.7 Earth years
Day	6 days, 9 hours, 18 minutes
Number of Known Moons	1
Axial Tilt	118°
Temperature	40 to 60 Kelvin
Apparent Visual Magnitude	13.7
Color	?
Mass	.0021 Earth masses
Density	.5 to 1.4 g/cc
Oblateness	?
Albedo	38 to 70 percent
Orbital Eccentricity	0.25
Orbital Inclination	17.2°
Average Orbital Speed	4.7 km/sec
Escape Velocity	1 km/sec
Discoverer	Clyde Tombaugh, February 18, 1930

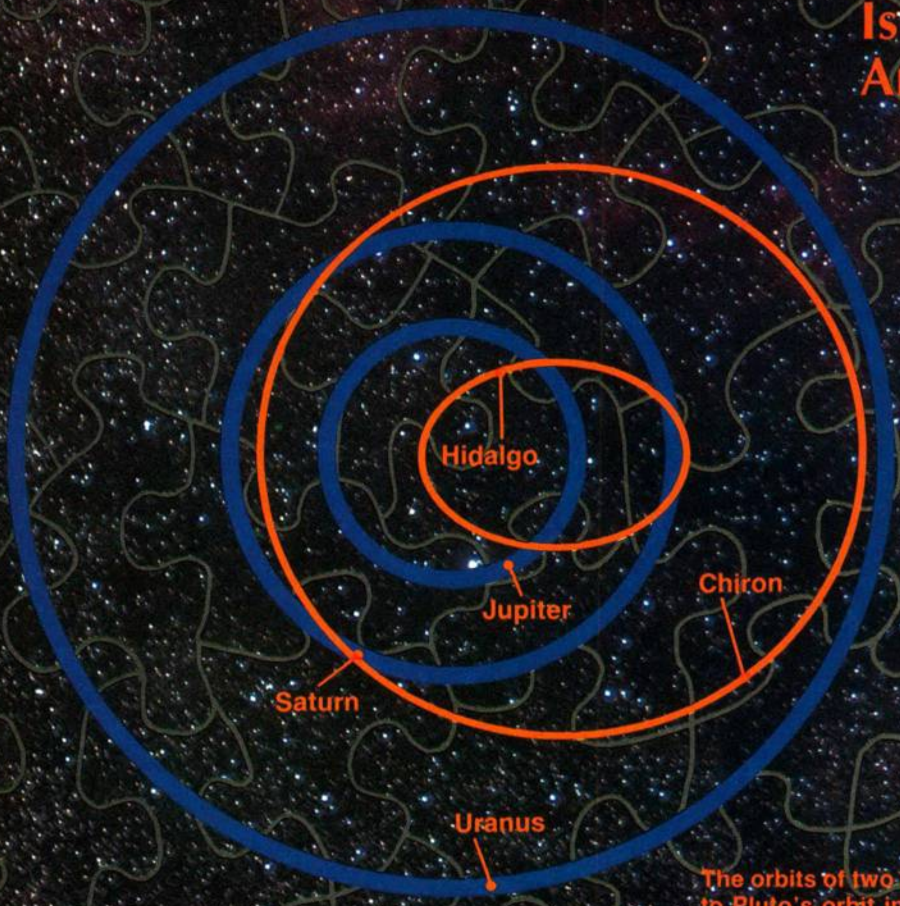
Charon

Apparent Visual Magnitude	15.4
Distance from Pluto	19,400 kilometers
Period of Revolution	6 days, 9 hours, 18 minutes
Diameter	Greater than 1,200 kilometers
Orbital Eccentricity	0.00
Orbital Inclination	0°
Albedo	?
Density	?
Mass	.0002 Earth masses (?)
Discoverer	James Christy, 1978


Jupiter
Neptune
Earth
Mars
Mercury
Pluto
Charon

Pluto's diameter compared to other planets, showing Pluto's relatively small size (in terms of mass, the difference is much more substantial). However, Pluto and Charon are much closer in size than any planet and satellite in the solar system.

Is Pluto An Asteroid?



The orbits of two asteroids indicate their similarity to Pluto's orbit in contrast to the orbits of all the other planets in our solar system. Hidalgo has an eccentricity of .66 and an inclination of 42°. Chiron possesses an eccentricity of .38 and an inclination of 7°.

would have found it in the 1910s.

Then what is Pluto? Perhaps it should be considered a very interesting asteroid. It may, in fact, be the largest in an entire belt of trans-Neptunian asteroids we presently know very little about. Furthermore, at least two other asteroids are quite similar to Pluto. One of these, 944 Hidalgo, which was discovered in 1920, orbits the Sun in a very eccentric orbit. At perihelion, Hidalgo lies closer to the Sun than Jupiter; at aphelion, it voyages farther than Saturn. Even more interesting — and more Pluto-like — is the asteroid 2060 Chiron. Chiron normally orbits the Sun between Saturn and Uranus, but at perihelion it lies closer to the Sun than Saturn.

Brian Marsden keeps track of asteroids for the International Astronomical Union. He believes Pluto is an asteroid (though he has given up on the big mountain) and suggests that, like all other asteroids with known orbits, it be assigned a number. Marsden even has a number: 330. Asteroid 330 Adalberta was supposedly discovered in 1892 but has not been seen since. Perhaps Pluto should formally be named 330 Pluto and join 944 Hidalgo and 2060 Chiron.

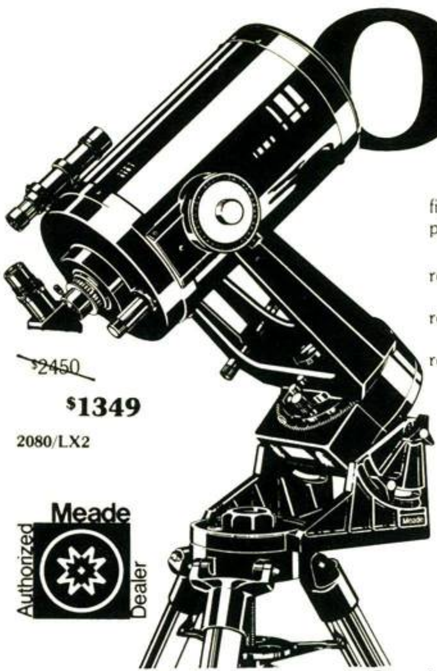
But calling Pluto a trans-Neptunian asteroid cannot diminish the fascination it holds for astronomers or the mysteries it still hides. In fact, this makes Pluto even more interesting. If Pluto is a building block left over from the formation of the solar system, it may be able to tell us things about the solar system's creation that no planet (all of which have undergone modification since then) can.

Yet Pluto's greatest legacy may be one far more precious to science in general and astronomy in particular: wonder. As we look to Pluto and the outer solar system, we gaze into unknown and unexplored regions of space.

Is there another planet out there? Though Tombaugh's search for planets went on for thirteen years following Pluto's discovery, none were found. Still, one thinks of the deviations in Neptune's motion from its expected path — deviations Pluto can no longer explain. One looks out beyond Neptune, beyond Pluto, and one simply wonders.

A doctoral candidate at Harvard University, science writer Ken Croswell's most recent contribution to ASTRONOMY was "Uranus: On the Eve of the Encounter," published in our Septemer 1985 issue.

Overstock Sale!



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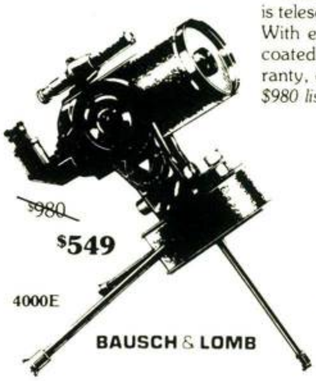

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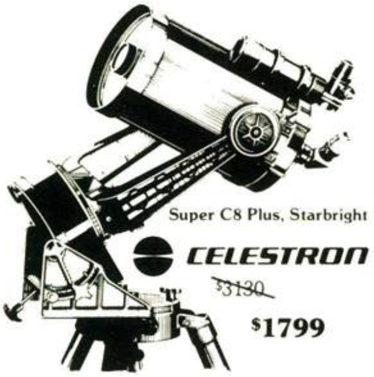

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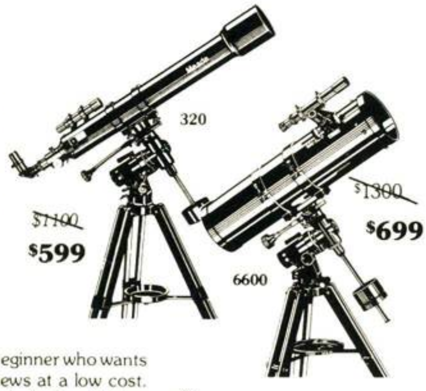

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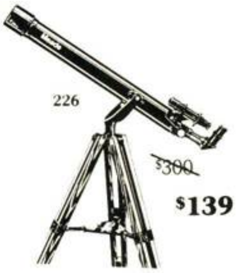

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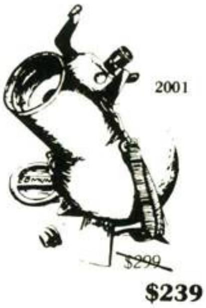

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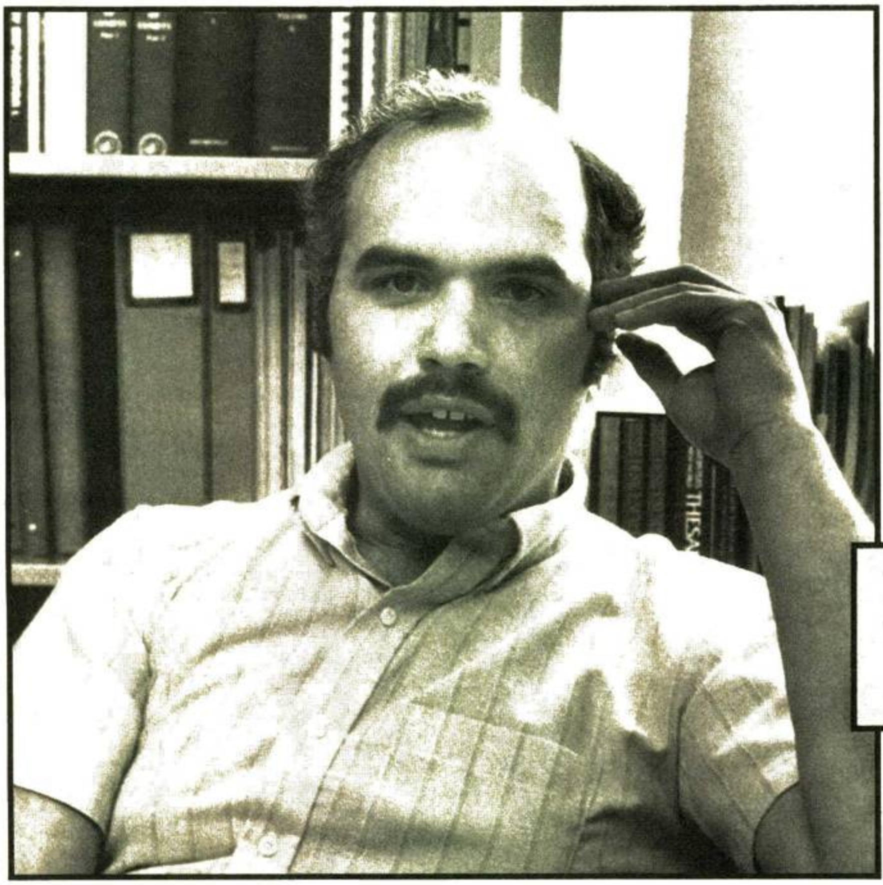

Steve Edberg: IHW's "Mr. Comet"

Steve Edberg is the Coordinator for Amateur Observations for the International Halley Watch (IHW). ASTRONOMY interviewed him in his office at the Jet Propulsion Laboratory in Pasadena, California, during the last week of January.

ASTRONOMY: Steve, what is the International Halley Watch? In two sentences or less.

Edberg: In two sentences or less, the International Halley Watch is a coordinated effort among professional and amateur astronomers to collect data and then have it compiled into the most complete collection of data ever put together in one place on a comet. In this case, Halley's Comet. That's the long and short of it.

ASTRO: What's your role in IHW? Where do you fit in?

Edberg: My role is primarily one of coordinating the efforts of amateur astronomers who participate in the Halley Watch.

ASTRO: And you were picked because you've been an amateur astronomer?

Edberg: That's correct, and because I have been active enough that I have connections spread fairly wide. I'm familiar with at least the amateur astronomical community in this country and, to a degree, around the world, and that helped. My efforts involve teaching amateur astronomers what observations are useful and, most important, how to make a good scientific observation.

ASTRO: Now, you're a solar astronomer . . .

Edberg: Yeah! (laughs)

ASTRO: Well, you were . . .

Edberg: . . . in an earlier life.

ASTRO: Did comet astronomy just happen to you, or was it something you decided to do?

"We're not going to have that long to study it . . ."

Edberg: My professional training, up until the Halley Watch, was in solar physics. But I've been observing comets, even as an amateur astronomer, back in 1968. Comet Tago-Sato-Kosaka was the first comet I saw. Prior to that I'd made unsuccessful searches for Comet Ikeya-Seki. When I was small — I don't know the name of the comet but it had to have been either Arend-Roland or Mrkos in 1957 — I remember my dad taking me out in the backyard and looking for that comet.

ASTRO: How long has IHW been in operation?

Edberg: Since 1981. The idea was first suggested in 1979 by Lou Friedman, who's now at the Planetary

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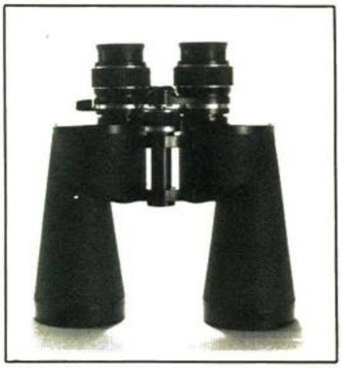

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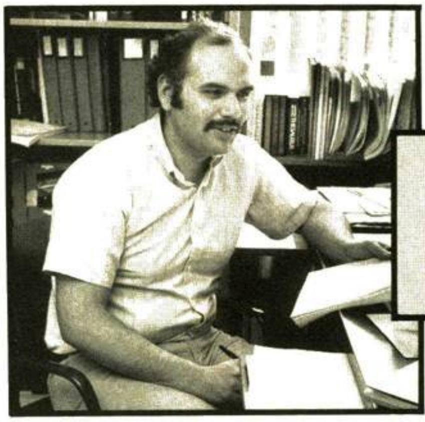
Society. The proposal was studied as NASA usually does, and in 1980 it was determined that it was indeed a good idea. By 1981 things got formalized and in '82 we decided this is what we want to do, this is how we want to do it, and we started doing it. The International Astronomical Union endorsed our program and endorsed the International Halley Watch as the sole organizing body for Comet Halley observations. With that kind of endorsement, away we went.

ASTRO: How much cooperation has IHW had from astronomers? I know that a lot of professionals tend to look down their noses at comet observations.

Edberg: Actually, their cooperation has been marvelous. It's ranged from individual astronomers right up to the observatories. They're giving extra thought to telescope assignments and they're keeping in mind that we have a huge perturbation in normal astronomy while Halley is here. They realize we're not going to have that long to study it, so they're helping us make the best of it.



ASTRO: Do you think that International Halley Watch helps the individual comet astronomer get observing time on the big telescopes?

Edberg: It certainly does. Halley Watch Days helped, too. They're days when we try to get coordinated observations from every discipline. Every astronomical technology that can observe the comet is encouraged to observe during those periods. The schedule was carefully thought out to minimize interference with the rest of astronomy. By getting everyone to work together, the synergism of all the technologies observing the comet in their large variety of ways will be much greater. Because of this, we're getting much more out of Halley than we would if we had only individual observations.

ASTRO: Well, you're coordinator of amateur observations. What can an amateur astronomer actually do? What are you having them do now?

Edberg: I'll break it down into three broad areas. The first is visual observations, the second is photographic observations, the third is meteor observations. Meteors are a whole separate animal, so we'll leave them out for now. Among the visual observations, we're interested in careful estimates of the comet's brightness. Observers compare the comet to a standard set of comparison stars listed in the Halley Watch amateur manual. You find the comet's magnitude by defocusing a star, comparing it to the comet, and deciding whether it's brighter or fainter. You have to estimate how much brighter or fainter, then compare it to a few other stars, and boom, you're done. It's pretty quick once you get in practice.

ASTRO: How are those observations useful?

Edberg: Well, in a surprising way. Professional astronomers don't make magnitude estimates, as a rule. But brightness estimates are used in the actual physical modeling — computer modeling of the comet for its gas and dust production rates.

"Will the darn spacecraft survive? We don't know."

ASTRO: Based on eyeball estimates?

Edberg: Yes. I've got a visually estimated light curve of Halley to the present. Let me get it out. (crinkle, crinkle.) Here. You can see estimates starting as far out as 3 AUs.

ASTRO: Okay, so one axis is estimated magnitude and the other's heliocentric . . .

Edberg: . . . yeah, heliocentric distance.

ASTRO: It looks like Halley's not getting brighter nowadays.

Edberg: Well, it clogged past the Halley Watch predictions last fall and seemed to be paralleling Joe Marcus' predictions for a while, but right now it's turning down some. What all this is telling us is that, first of all, we don't understand the behavior of the comet very well.

ASTRO: How will these data be used?

Edberg: The graph we're holding here, in fact, is going to be used in the modeling to be done prior to a meeting to discuss the Giotto encounter. It will be used to get an estimate of the dust and gas environment. Will the darn spacecraft survive? We don't know. We'll ultimately find out, but I hope not the hard way.

ASTRO: What's happening at the beginning and the end of each observing period?

Edberg: The estimates start out too low and end too high. It's a weird effect, I know, and it shows on both aperture-corrected and uncorrected estimates. In fact, I can show you (rustle, rustle) the same effect in 1910 data.

ASTRO: There it is!

Edberg: See how the estimates run: up, down, up, down, up down, up, down? (laughs) I don't know what to make of that.

ASTRO: It's a "hopefulness effect." Observers always want the comet to get brighter during each Moon-free observing period.

Edberg: Yeah, probably.

ASTRO: So that's photometry.

Edberg: Right, and it's only half the visual effort. The other half I had the opportunity to do myself last night. At high magnification you look at Halley. It isn't just a blob; it wasn't last night, anyway. It was very reminiscent of the pictures of Comet Bennett; if you can remember, there was more tail coming off of one side of the coma than the other.

ASTRO: Some of the photos our readers have sent show that very markedly.

Edberg: That's right. I have seen it in my pictures, too. Last night we were seeing it visually. I think we were also seeing a jet last night. The conditions just weren't real good. Chuck Morris [a comet astronomer] and I were out together. Neither of us is an artist, so the drawing that came out of it isn't going to be the best.

ASTRO: Why make drawings in an age of photography and CCDs?

Edberg: We want drawings because we like to compare what our eyeballs are seeing to what both our old-fangled photography and new-fangled CCD cameras can do. They're good for comparison, something we intend to keep in the archives. They also have value in the historical context, too. What was Herschel seeing in 1835? How do his drawings compare to what we're seeing now, and how do current drawings compare with reality, at least as photographed?

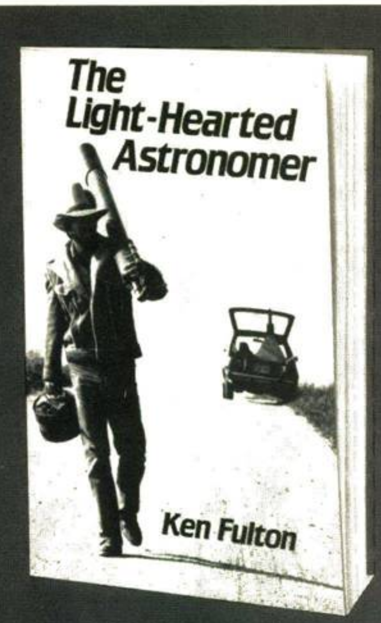
ASTRO: That seems useful enough.

Edberg: It is. And visual observations pick up lots of useful stuff. John Bortle — he's a big comet observer — says that every couple of days a bright, very stellar nucleus appears in the comet. Perhaps we are seeing the effect of rotation on the active areas of the comet. That is the sort of visual observation that can be quite useful.

ASTRO: What about photographic work?

Edberg: This is an area where the primary use is mostly as a back-up to professional activities.

ASTRO: Do you want their original



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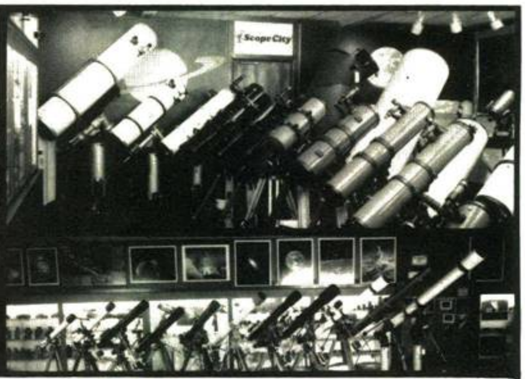

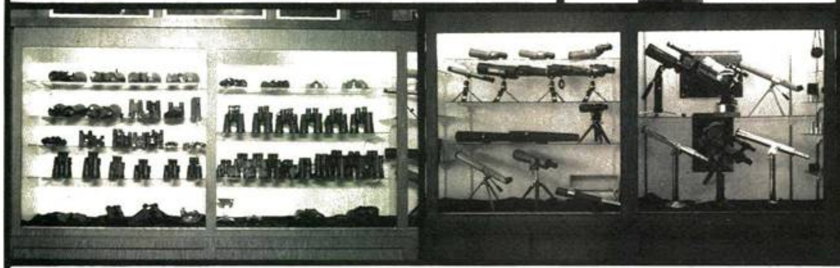

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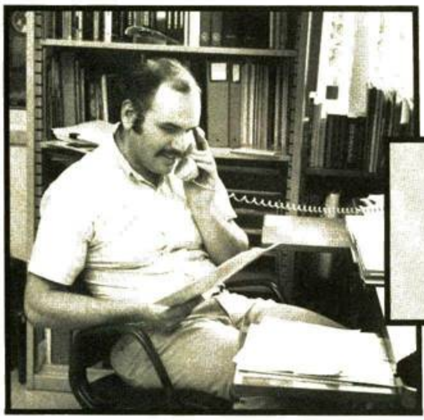
Edberg: When anybody asks — and even when they don't — I tell them, "Don't send me originals." Putting on my hat as an amateur astronomer, I don't like giving up my own originals. I see no reason for their pictures to end up in a filing cabinet here. If we have the records we ask for, observers can send prints, duplicate slides, or whatever. We don't need the originals. And when all the dust settles, we're going to produce a huge catalogue, which will be distributed to the professional discipline specialist teams. And they can say, "Gee whiz, we really need to have a photograph on March 15 at 3:45 UT." And they will be able to go down the list and find out that Mr. John Jones took a photograph at 3:40 UT. Bingo, it's just what they need.



ASTRO: Then they get in touch with you . . .

Edberg: . . . and we arrange to get in touch with Jones to see about borrowing his original. Jones might want the original back or he might settle for a good duplicate made by the team, or whatever. Meanwhile, we'll get the photo reports catalogued so we know what's out there.

ASTRO: One of the functions of the IHW manual seems to be getting across the importance of keeping good records.

Edberg: That's right. It's none too easy. A lot of thought went into the report forms. Several forms turned out to be deficient, even after all the thought, so updates have been sent to all registered observers. That doesn't mean we'll toss out observations if one box on the report form isn't filled in.

ASTRO: Photographers sometimes don't bother to record the times of their exposures?

Edberg: Yeah, and we'd like it within a thousandth of a day, which sounds ridiculous. But that's one and a half minutes. Anybody can afford a watch that's good enough. The problem is that a lot of astrophotographers can't be bothered taking notes. They'll say, "Oh, I'll try a ten-minute exposure," and they'll come back five or ten or fifteen minutes later and end it. It gets awfully tough to include something like that in the Halley Archive.

ASTRO: So a good part of what you are doing is making sure that the amateurs collect data that can be used.

Edberg: That's right. It's part of the whole educational process.

ASTRO: How many active observers do you have?

Edberg: Well, at present that's a hard question to answer. There are over 1,000 registered observers. And that means they got the Halley Watch Amateur Manual, filled out the Observer Index form in the front, which specifically instructs them to read several sections in the manual before filling it out. I wanted people to be aware that if they wanted to participate we would love to have them, but they should understand what they are biting off. It's serious work. They can't be as casual about it as they might be just going out and observing. More than a thousand forms have been returned now from fifty-five countries. That's a pretty impressive statistic, I think. It's much harder at this point to gauge the actual number of active observers. If the IHW Comet Crommelin trial run is any guide, only 10 percent of them are going to be actively submitting observations.

"Hello. International Halley Watch . . ."

"I see no reason for their pictures to end up in a filing cabinet here."

ASTRO: Earlier you mentioned meteor observing?

Edberg: Oh yes, the meteors. I almost forgot. The two showers, the Eta Aquarids and the Orionids, are material from Comet Halley. It might not be from this return of the comet. It may be from the return that was 2,000 years ago or a return that was even earlier. But it's old stuff. Just the same . . .

ASTRO: . . . it's stuff from the comet.

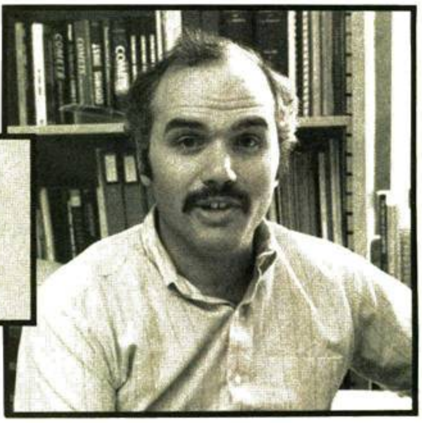
Edberg: Yes, stuff that's been shifted in its orbit so it hits Earth. The gravitational pull of the planets and solar radiation pressure move it out of the comet's orbit. You can learn something about the composition if you get a good spectrogram. You can learn something about the orbital mechanics of the dust particles by studying the showers themselves. When did the showers peak? How large is the peak? How many meteors, in other words, per hour? And is there anything unusual about these meteors? You do some triangulation. Do they start and burn out at higher altitudes than average, at lower altitudes than average, or just average? Are they fluffy or solid? Are they moving faster than average? It turns out, yes. This is an area where there are few active professional meteor astronomers. They need all the backup they can get.

ASTRO: So the observations will be processed . . .

Edberg: . . . and a lot will end up in the archives. Visual observations also go directly into the archives.

ASTRO: What will the archives look like?

Edberg: Well, here's an early draft of the Comet Crommelin archive. Look at what's in it. First there's ephemeris information for where the comet was, its RA, declination, and distance — all that sort of thing. For this date, we only have amateur observations. One, in fact, by John Bortle: "The comet wasn't seen." A negative observation is still useful.



ASTRO: The next page doesn't have much more on it.

Edberg: Just one astrometric plate and that's all for that date. You get deeper on into this. (flip, flip) Just for the fun of it (flip, flip) here you see some photometry and polarimetry. (flip, flip, flip) Radio studies really picked up in February. They were working hard then because that was close to perihelion for Crommelin.

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(Photo Not Available—Appearance Identical to 2080/LX3, But Larger)

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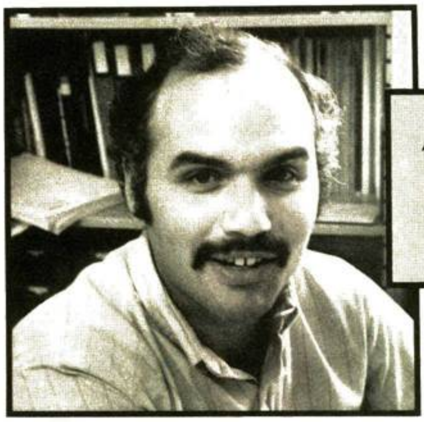
Here's an observation. The time was February 24.16, magnitude 8.1, the Morris method was used. An AAVSO star chart was used for comparison stars. The coma was 7 arcminutes in diameter, it had a degree of condensation equal to five, and no tail was visible to that observer.

ASTRO: It also tells the instrument he was using.

Edberg: A pair of 20x80 binoculars, in fact. Here's somebody else using a Schmidt-Cass f/10, 20cm, and he was getting a magnitude 7.3 using the Sidgwick method. He saw a 3-arcminute coma. There's part of the aperture correction business. The guy with the 20x80s saw a bigger coma. Hopefully with Halley, someone will be able to take the data, whatever type it might be, and correlate it. It should be very interesting to have such a broad database, especially one with lots of amateur stuff, to try and understand both the physiological and the physical effects of making an observation of a comet.



ASTRO: The archive will be a giant day-by-day compendium of all the observations, by category, with all the relevant information extracted from your forms?

Edberg: That's right. And for all the professional networks, too.

ASTRO: Okay, the Crommelin Archive is a book about three-quarters of an inch thick. How big will the Halley Archive be?

Edberg: Well, the final version of Crommelin is about a fourth again as thick, so about an inch thick. For Halley, we'll have something like twenty volumes this thick. Until we got a new tape drive *for the computer*, it was going to end up being on 300 tapes, and that would fill a room this size. We have a better, higher-density tape drive now, so the data tapes won't be quite the problem they looked like they were going to be. We plan to put the data on compact disks so people will have digital data at their fingertips.

ASTRO: Is this just the amateur stuff?

Edberg: No, this is the whole thing.

ASTRO: So if astronomer X at observatory Y took a picture with telescope Z and did a certain type of observation, I'd be able to find an entry in there, not the full data he took, but just the fact that he took it on that day.

Edberg: Yes. In the written archive that is the case. Mostly, it will be an index to observations. But the large scale phenomenon network — the tail studies network — is planning to put a thousand digitized images into the archive. Pictures would be digitized and available on a compact disk. That compact disk is going to be readable on something like an IBM-PC and I imagine others, too.

ASTRO: How many compact disks will it take? They hold half a gigabyte each, I think.

Edberg: That sounds about right. I don't know the exact number, but it shouldn't be more than ten or twenty at the most. The compact disks will also have all the text in the archive on them, as well as spectra. It should make the comet observations extremely accessible to everyone.

"You still have to pay fifty cents for a can of Coca Cola."

ASTRO: Has anyone ever attempted such a massive compendium of such a wide variety of data before?

Edberg: Certainly not for a comet. I am reluctant to go beyond that, though. There's a lot of digitized data on stars in the National Data Center. Another contender is the people who are putting out the compact disks of spacecraft data. Those are very large data sets.

ASTRO: If the IHW is successful, do you think that it will either continue for other objects or be done again?

Edberg: There already is sufficient interest that one of the things we will be discussing at our Paris meeting, in fact, is maintaining an international comet watch of some kind. There's a big index for asteroids, for instance. The same thing would be done now for all comets and that would prove very useful in planning spacecraft missions to comets.

ASTRO: Steve, let's get back to amateur astronomy for a bit. I know there's been a bit of controversy about who saw Halley first this year . . .

Edberg: Steve O'Meara beat everyone. Steve didn't get the notoriety he deserved, first of all. But second, it really wasn't that important. It's an interesting bit of data from the physiological point of view and for the comet itself. Of course, he made a visual magnitude estimate. That will help. It's too bad we didn't get more estimates before conjunction last spring.

ASTRO: Wasn't there a great race to be the first?

Edberg: They were fighting to be second, even though they didn't know it. Steve clearly had first place sewn up. The vehemence, the attacks, the anger of some guys claiming, "I saw it first," and others saying, "No, you didn't either." It astounded me. I heard a lot of that kind of thing.

ASTRO: Were all the reports believable?

Edberg: No. It was a difficult observation to begin with. The comet was immediately post-conjuction under less than ideal conditions in a twilight sky. There were guys who made drawings that clearly showed they hadn't seen it. They wouldn't believe me when I told them what they saw was not Halley. I mean, what do you do then?

ASTRO: Sounds awful.

Edberg: Yes. One guy was way off in right ascension and significantly off in declination, too. The observation just didn't fit. But, no, it had to be. So there's one guy going around believing he saw the comet first, and I suppose that's fine . . .

ASTRO: Why not?

Edberg: . . . but then I find out he hasn't even gone back to see the comet again! Four weeks later and he hadn't bothered to take a second look. It was purely an effort for some glory. Everyone likes the glory, but we could have used more science out of it. Now, maybe that's a funny thing for me to be saying, considering that Chuck Morris and I saw Halley naked eye first.

ASTRO: You were simply the first people to try it.

Edberg: Well, I think that's it. No one expected to see it naked eye until December. Lots of people were going to have a crack at it then, but we just went ahead and tried in early November. We certainly weren't looking for glory — and we didn't expect the response our sighting got. That surprised both of us greatly.

ASTRO: How do you feel about it now?

Edberg: Well, it's neat we saw it, but it wasn't hugely important sciencewise. And it doesn't end up doing much for you in the end. You still have to pay fifty cents for a can of Coca-Cola.

ASTRO: Steve, thanks for talking with us.

— *Richard Berry*

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#142 3" Equatorial	48X, 67X, 96X, 131X, 200X	4°20′	75 mm, f/16	8X—30 mm, 4°22′ field	47 in.	59 in.	46 lb.
#131-C 3" Compact Equatorial	48X, 67X, 96X, 131X, 171X, 200X	4°20′	75 mm, f/16	8X—30 mm, 4°22′ field	19 in.	60 in.	32 lb.
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ASTRONOMY
In Focus

A Vote For LPS Lighting

Sir / I feel that low pressure sodium (LPS) lights are a wise choice for lighting our cities and communities. In the long run we would save energy and money as well as help professional and amateur astronomers with their never-ending exploration of the universe.

The computer-generated image showing the distribution of lights in North America that appeared on pages 16 and 17 of your November issue reminds me of a huge birthday cake with millions of candles. If you ask me, it's time to blow out those candles! Then we'd see dark skies again, like those over Nevada.

Hopefully the dark skies bill (Forum, October 1985) proposed by minority leader James R. Hurley of the New Jersey State Senate recommending that municipalities practice some type of light dimming will be the first of many such bills to aid in the darkening of overly bright skies.

Rick Hays
Tulare, CA

Halley Ad-age

Sir / Halley's Comet has been familiar to all cultures and advertising agencies on Earth, both in modern times and in ages past.

What probably hasn't been recognized is the peculiar way comets affect the psyche of humanity. The dangers of comet gas don't compare to the effects of advertising hype. Indeed, the public relations that comets are given assault our senses like no comet gases ever could.

If it takes a comet to arouse collective interest in astronomy, then I'm all for it. I envy the optimism and pure naivete of those budding astronomers living in metropolitan areas who bought 2-inch shopping mall telescopes. One has a better chance of seeing Halley through a kaleidoscope at high noon.

I was seduced by Halley at a dark site 180 miles from home on an arctic morning, where I saw the faintest and most delicate symmetry of the "airiest part of nothing." It was the thrill of a lifetime to confirm that my new mountain parka lived up to its advertising claims better than Halley's Comet!

What's wrong with expecting to see a blazing fireball arcing across the heavens replete with dancing plumes flicking fiery tongues at the cold void, the Little Prince hanging from his wondrous transport in smug delight? I just don't know.

I guess it's all part of life and human nature to hope for the best and believe everything we read.

William Weiss

Another Satisfied Halley Watcher

Sir / I just had to write and let you know about my Halley encounter. Living at 45° north latitude, I wanted to see the comet before April when it would be too low in the sky. Unfortunately, the winter skies over my home town of Aberdeen have been less than ideal for observing the comet. When there wasn't cloud cover, there was always a Full Moon. I began to think that I wasn't going to get a chance to see this famous object.

There were more clouds in January followed by February with the comet behind the Sun. Then on the morning of March 15, I drove out to one of my favorite observing sites where there's a clear view of the sky in every direction. The sky was pitch black and the air was steady. The stars shone down like beacons and the Milky Way was really living up to its name.

At about 5 a.m. I scanned the southeastern sky east of Sagittarius and, Bingo! There it was, and brighter than I had expected. There was no mistaking it since the tail was so long it hardly fit in the binocular's field of view. At 5:17, just as I was looking at Halley, a bright meteor shot above it. How I wish that I had been taking a picture at that moment!

I continued to observe until twilight started to diminish the comet's brightness. By 5:25, all I could see was the nucleus. I managed to watch the nucleus for another ten minutes before it faded completely.

It was a moment that will live with me forever. To those of you who are wondering: yes, it was very much worth getting up for.

Mark Schnoor
Aberdeen, SD

A Reflecting Sundial

Sir / Some weeks ago I happened to read an article on sundials in ASTRONOMY (Equipment Atlas, January 1986). I thought I would tell you about the sundial I set up at a trailside museum in Montgomery, where I used to be curator.

The sundial's basic component is a small mirror about 1 by 5 inches in size. It is placed in a convenient south-facing window at the upper part of the frame or near the lower sash. The Sun is reflected upon the ceiling and moves across the surface at the rate of about one inch every five minutes.

Timing the reflection with a clock helps one lay out the hours and half-hour marks. Mine works well from about 10 a.m. to 4 p.m. A further embellishment is the use of a prism placed upon the mirror. This gives off intriguing, colorful streaks of light.

As the months pass, the reflection moves away from the numbers — deeper into the room in the winter and closer to the window in the summer. (I *countered with two* scales: Daylight Savings Time near the south wall and Eastern Standard Time farther inwards.)

The use of the prism has one drawback: it needs full Sun for the sundial to work. With just the plain mirror, however, hazy days are still adequate.

Henry J. Stark
Montgomery, NY

HST a Tribute to Its Builders

Sir / I have just finished reading the article on building the Hubble Space Telescope's optical system (January 1986). Until now I did not realize the full extent of the problems encountered by the builders of this magnificent machine. Having worked with fiber composites, I fully appreciate the great difficulties presented by the hygroscopic behavior of the graphite/epoxy metering truss. The article suggests that the exploration of any frontier is a joint effort by many talented people who must remain behind the scenes. The images produced by HST will be a tribute to these people.

S.A. Umar-Khitab
Hamilton, Ontario, Canada

Praise for Binoculars

Sir / After unsuccessfully attempting to see Halley's Comet for over two months, I finally met with success.

On December 13, using 10x50 binoculars from my backyard in severely light-polluted metropolitan Chicago, I spotted the very dim circular patch of fuzzy light, barely brighter than the sky background.

I was quite surprised to see the comet since the faintest stars visible from this location are about magnitude 4.5. The light pollution is so severe that M-42 appears as a dull, washed-out object even in a large telescope.

Though a low-cost pair of 10x50 binoculars showed the comet, it was totally invisible using an 8-inch f/6 Newtonian. The view was hardly awe inspiring, but it did teach me great respect for binoculars as an astronomical viewing aid that is second to none in certain situations.

Karl Fabian
Chicago, IL

A Handy Star Pointer

Sir / Have you ever tried to point out a nebula or galaxy to a friend? It takes ten minutes to hop from star to star before you finally end up at the insignificant speck that is your destination, only to find that your friend has ended up somewhere else!

Recently I stumbled upon an idea that aids in pointing out objects in the night sky. Because I deliver pizza at night and can never find the address I'm looking for, I bought a halogen flashlight. Its bright, narrow beam suggested to me that the flashlight might also work as a star pointer.

When I tried it, it very effectively picked out individual stars. However, it also emitted a broad ring of diffuse light that would blind dark-adapted eyes. To remedy this, I made a shield out of 2-inch black ABS pipe that fits snugly over the head of the flashlight. It directs a tight beam up to the sky without throwing stray light anywhere.

The pipe can be found in the plumbing section of any hardware store for about 65¢ a foot. I've found the most effective length is 8 inches. The printing on the outside surface of the pipe can be easily removed with acetone; this will also leave the outside shiny to match the flashlight. A good halogen flashlight costs about $8.

For less than $9 you can have a very effective, lightweight star pointer that can be used at the darkest of star parties.

Brett Drury
Colorado Springs, CO

Saved From 48,000 Keystrokes

Sir / I would like to let you know how much I am enjoying the STARS.BAS program (Equipment Atlas, August 1985) to plot stars on my Commodore 64 computer. I must confess that I was lazy and downloaded the database from CompuServe rather than keying it in myself. I did, however, key in the Messier Catalogue to add those objects to my plots.

Brian S. Rickard
Denver, CO

Behind the Scenes

1027: Here We Come!

This issue of ASTRONOMY is the last to be produced at our 625 E. St. Paul offices. A week from today, on May 5, our editorial staff will move to new offices on the eighth floor of the Kalmbach Building, and Dana-Lynne Terry, our advertising coordinator, will join Kalmbach's advertising department on the sixth floor. Our new address is: 1027 N. Seventh St., Milwaukee, WI 53233. Our new phone number is: (414) 272-2060.

ASTRONOMY has, up 'til now, used an "outside data service" in Chicago to track your subscription. Most of the time, everything went well and your magazine arrived reliably every month. But there were the inevitable problems. When these did crop up, our staff had to find your name and subscription, using microfiche "updates" of the master circulation lists. Since a new fiche came out each month, the computer might know we had received your check but our circulation clerk might not because the microfiche didn't show it. This caused a lot of frustration for both you and us.

But hooray! Kalmbach has added 600 megabytes of disk storage, 4 megabytes of RAM, and three new terminals to its in-house fulfillment computer to take care of the ASTRONOMY and ODYSSEY circulation lists. The switchover should be complete by the time you read this. If you have problems with missing issues, late delivery, or damaged magazines, we'll be able to handle the difficulty "on-line" — faster, better, and more efficiently than ever before.

We all wish the Post Office could give every magazine it handles the "kid-gloves" treatment. We want ASTRONOMY to reach you in the same pristine condition it leaves the printer. After a long search, we've found an excellent solution. Beginning with the August issue, ASTRONOMY will be mailed in a tough, watertight, poly wrapper. These plastic wrappers protect magazines better than any of the competing wrapper types we've seen. We hope you'll like the improvement.

Amidst the hustle and bustle, I sometimes wonder how the magazine's founder, Stephen Walther, would have viewed the sale of the company he created thirteen years ago. Had he lived, I am certain he would have resisted it. But I am equally certain he would be proud of what ASTRONOMY is today, and of the dedicated people who nurtured his dream — of an astronomical magazine for everyone — during the eight years since his death. We now enter a new era in this magazine's history.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

ASTRONOMY Reviews

Living the Sky: The Cosmos of the American Indian
Ray A. Williamson
366 pages, hardcover, $19.95
Houghton Mifflin Company (1984)

When most of us think of observatories, we envision nights spent on a mountain top guiding a telescope while some electronic instrument counts photons or photographic film preserves an image for later study. And when most of us consider prehistoric astronomy, we think about ancient Greece or perhaps Babylon or China.

But imagine, if you will, a prehistoric astronomical observatory that is literally in your own backyard — an observatory that may have been there centuries before European explorers first set foot on North America. The Oglala Sioux, Zuni, or Skidi Pawnee Indians probably looked at the sky with much the same motivation as contemporary astronomers: to understand the cosmos.

Archaeoastronomy combines the sciences of archaeology and astronomy. The goal of the discipline is to uncover the cosmological thinking of past civilizations. Typically, archaeoastronomers have studied sites like the pyramids of Egypt, Stonehenge, or the temples of ancient Mexico. Reading an astronomy text might lead you to believe that the original inhabitants of the United States and Canada had little or no interest in the sky. In this book, however, Ray Williamson has gone to great lengths to introduce the reader to the sky of the American Indians.

My own fascination with Native American astronomy began when I read John Eddy's article, "Mystery of the Medicine Wheels" in *National Geographic* (January 1977). In August 1977, I made the first of my five visits to the Medicine Wheel high atop Medicine Mountain in Wyoming's Bighorn Range. There, twenty-eight rock spokes radiate from a central cairn to form a roughly circular "wheel" 24 meters in diameter. Six smaller cairns located around the circumference of the wheel provide sighting positions.

That fall, I was going to teach my first college astronomy class and I was determined to include material on Native American astronomy. At that time I was hampered by a lack of comprehensive, readable references to which I could direct my students. A well-known and respected text like George Abell's *Exploration of the Universe* contains nothing about Native Americans and the sky. Likewise, the second edition of William Hartmann's *Astronomy: The Cosmic Journey* makes only passing reference to sites such as Medicine Wheel, though Hartmann had included much more material in his first edition. On the other hand, Michael Zeilik (who has done research at Chaco Canyon in northwestern New Mexico) includes an excellent narrative in his astronomy text.

Williamson has written a popular book that is useful to teacher and student alike. He discusses the entire realm of Native American astronomy, principally physical remains and legends. Ruins like Casa Rinconada in Chaco Culture National Historical Park or Wyoming's Medicine Wheel show some type of alignment with astronomical events such as the summer solstice sunrise or the vernal equinox. Mounds such as the Cahokia Mounds in Illinois often show an alignment or at least an astronomically significant design. Oral traditions that the Indians passed to later generations recount a unique understanding of the sky. Finally, Williamson provides descriptions of ceremonies tied to astronomical events — for example, the heliacal rise of Venus.

Special mention is made of rock art. Petroglyphs (images etched in stone) and pictographs (paintings on rock) preserve impressions of the sky or unique events such as the Crab Nebula supernova of 1054. Many archaeoastronomers believe a pictograph at Chaco Canyon records the appearance of the 1054 supernova near the crescent Moon. The configuration of the supernova and Moon would have been visible from the southwestern United States at that time.

Williamson's theme throughout the book is that Native Americans had a pervasive need for a calendar by which to order their lives and rituals. "For most Native Americans, reckoning time was for the sake of integrating their lives with nature and with the supernatural influences that pervaded their universe."

Because the book is a popular treatment, the analytical content is limited; researchers looking for more advanced information will need to consult the references cited. Williamson's narrative approach is very good, however. I felt like I was there with him as he labored to unlock the secret of Hovenweep Castle, a tower ruin at Hovenweep National Monument in southwestern Colorado.

My criticisms of *Living the Sky* are few. I might have included more maps locating the sites with respect to major highways and cities. On the other hand, maybe this isn't so bad after all. Williamson recounts enough stories of defaced and disturbed sites that perhaps it's better that he didn't give directions too explicitly. In any case, National Park Service rangers will gladly direct visitors who have legitimate interests to the more remote or fragile sites.

Second, because of my own interest in Medicine Wheel and the natural beauty of the Bighorn Mountains, I would have included a photo or two of this site. Instead, illustrator Snowden Hodges has provided a fine line drawing of the summer solstice sunrise as viewed over the rock cairns of Medicine Wheel. Color as well as black-and-white photos provide ample illustrations of the other principal sites.

Whether you are a professional astronomer, teacher, backyard stargazer, or student, read this book. It will expand *your* universe. It may affect you like it did me: I spent two weeks in August last year exploring Canyon de Chelly, Mesa Verde, Hovenweep, and Chaco Canyon.

Living in the 20th-century computer age, we tend to segregate various facets of our lives. Williamson's theme and conclusion reflect the integrated nature of life for the American Indian:

"The sky turns, and in turning, measures out our lives. To live in harmony with the world and its cycles is the goal of traditional Native Americans. Their patterns for living derive from a deeply held attention to the rhythms of the sky and Earth. The lessons of archaeoastronomy and ethnoastronomy instruct us that whether as architects, weavers, hunters, potters, or storytellers, traditional Native American men and women weave their perceptions of the celestial patterns into their lives in order to participate directly in the ways of the universe." *Mark Hollabaugh.*

Venus, An Errant Twin
Eric Burgess
160 pages, hardcover, $24.95
Columbia University Press (1985)

In the eyepiece, Venus is a dazzling and brilliant, but featureless, object. Occasionally it appears like a crescent or a gleaming disk. At other times it looks like neither as it progresses through its Moon-like phases. The planet's bland appearance gives no hint of what lies hidden below its obscuring cloud layers. Until recently, not much more was known about Earth's nearby planetary neighbor than what could be seen in a good backyard telescope. Exploratory probes during the past two decades have radically changed all that. Once mysterious, Venus is now known as a place of immense heat and pressure, a suffocating and desolate landscape clothed in corrosive mist and haze.

Veteran science writer Eric Burgess has pulled together the major known facts about Venus, organized them neatly into an easily followed chronology, and presented them in a clear, non-technical style. The result is an informative, well-illustrated volume that will be useful to readers at all levels of expertise and interest.

Commencing with a short examination of the cloudy planet's observational history, the bulk of the volume concentrates on the period from 1961 (when the first Soviet Venera probe was launched) to 1984.

The initial chapters of the book describe the Venus space probes of both the United States and the Soviet Union. Following this, Burgess gets down to specifics in the third chapter, "The Veneras: Red Flags on Venus." This is a fascinating look at the highly successful Venera series. Each of the sixteen Soviet ventures is detailed in an event-by-event manner that helps to illuminate the often clandestine Soviet space projects.

The author compares the Soviets' strong commitment to planetary exploration with that of the United States, which has been characterized by erratic funding. Burgess writes: "The U.S. space program might be described as resulting from the dedication of small groups of scientists rather than from any imaginative government or political planning." Perceptive commentary and a willingness to speak his mind give Burgess' book a flavor that many readers will find refreshing in its advocacy. "The triumphs of the American space program," he continues, "are monuments to those individual teams who made things happen on time and within costs."

But Burgess goes beyond chastising as he accurately describes the failures as well as the successes of Soviet and American attempts. He captures the essential flavor of the Venus projects from the initial planning stages and the actual launch to the eventual entry into the planet's atmosphere.

What have the probes found? They have revealed that the atmosphere of Venus is a number of fog-like layers of mist with few, if any, localized structures such as clouds or storms. The author describes the landforms of the planet's surface, its absence of a magnetic field, its volcanic activity, and the possibility that in the remote past great oceans may have washed the planet's shores.

Why is Venus so vastly different from

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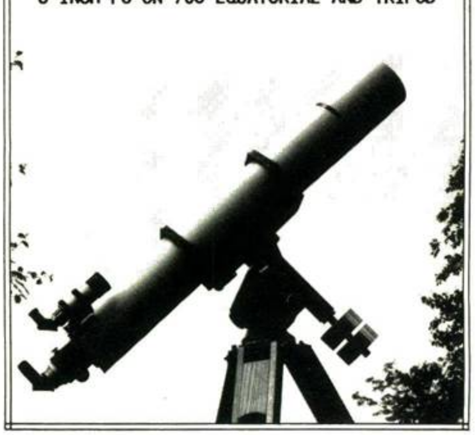

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Earth? The reasons are many, but Burgess suggests that in a larger sense, we're not going to get many good answers to this driving question until governments respond with adequately funded exploration programs and an ongoing dedication to research. *Gail O. Clark.*

Astrophotography:
A Step-by-Step Approach
Robert T. Little
79 pages, hardcover, $19.95
Macmillan (1985)

Backyard astronomers often learn about astrophotography alongside a master; this is how I learned to take pictures of the sky and I'm sure it's how many ASTRONOMY readers were instructed, too. Seeing someone take pictures of the sky and getting an in-person explanation of what's going on is the perfect way to get acquainted with such a complex and tricky subject.

However, if you don't have a teacher handy, the next best thing is a good astrophotography guidebook. A number of astrophotography guides exist; unfortunately, virtually all of them are beginning to show their age.

The often-reprinted *Outer Space Photography for the Amateur* by Dr. Henry E. Paul — a classic since its first printing in 1960 — has become badly outdated. Its emphasis on surplus lenses, old Petzval portrait lenses, and ancient plate emulsions is unrealistic in today's market dominated by Schmidt-Cassegrains and hypersensitized Tech Pan. Dr. Paul learned his craft during the pioneer stage of the hobby when astrophotographers were few and tough. When the lenses didn't exist, these photographers rolled up their sleeves and *made* them.

In light of the need for modern astrophotography books, I welcomed the appearance of Robert Little's *Astrophotography: A Step-by-Step Approach*, hoping it would report what has happened in astrophotography during the last ten or fifteen years. Unfortunately, Little's book is not much more than a spotty introduction to the subject. I should have been tipped off by the book's length: 79 pages with many photographs and little room for text.

The first major hole is Little's neglect of film hypersensitization. He briefly mentions it and then drops the subject. This exciting new technique deserves at least one chapter, if only because most astrophotographers now use relatively slow f/10 Schmidt-Cassegrain optical systems. Hypersensitizing is a convenient alternative to using a cold camera, which is the other way to suppress reciprocity failure. I looked through the book in vain for a single photo taken on hypered Technical Pan 2415, the new standard film for astrophotography.

Another weakness in Little's coverage is his failure to mention equatorial platforms such as Poncet, Haig, or Scotch mountings. These platforms are excellent for budding astrophotographers who want to dabble in taking pictures of the sky before making the commitment (and the considerable investment) to purchase more sophisticated equipment. Besides giving potential astrophotographers a taste of the hard work connected with the hobby, these platforms are a great way to inexpensively generate some beautiful photos. It's the next step up from simple tripod pictures.

Things I liked about this book included a warning against using cameras that don't have a manual mode of operation. Unfortunately, it seems that the number of cameras that can handle long exposures without using batteries is rapidly decreasing. Another useful piece of advice was to get a clear condenser for the focusing plane of cameras that will accept them. Not seeing what you're photographing in the camera has to be the most exasperating aspect of 35mm deep-sky astrophotography. Good instructions for field-aligning a telescope's polar axis are included in the book.

Even these good features don't save this dismal work. *Astrophotography* could have been a great book if it had contained twice as much text and included material of more interest to advanced astrophotographers. Absolute beginners should be warned that many of today's techniques for elementary astrophotography are ignored; advanced photographers should be warned that there is nothing here for them. And everyone should be warned that the list price of $19.95 is excessive for this slim volume. *Dick Suiter.*

Space, the Next Ten Years
Ted W. Jensen, ed.
170 pages, paperback, $25
Univelt (1985)
[Publisher's address: P.O. Box 28130, San Diego, CA]

"Our symposium goal was to present an opportunity for speakers from many of the space-related disciplines to come together and present their views as to where our nation should be going in space over the next decade." Speakers at the symposium, held in Colorado Springs, Colorado in November 1984, included George A. Keyworth, James Beggs, Jules Bergman, Kenneth Adelman, Edward Teller, and Lt. Gen. James A. Abrahamson.

The Creation of Matter
Harald Fritzsch
307 pages, hardcover, $19.95
Basic Books (1984)

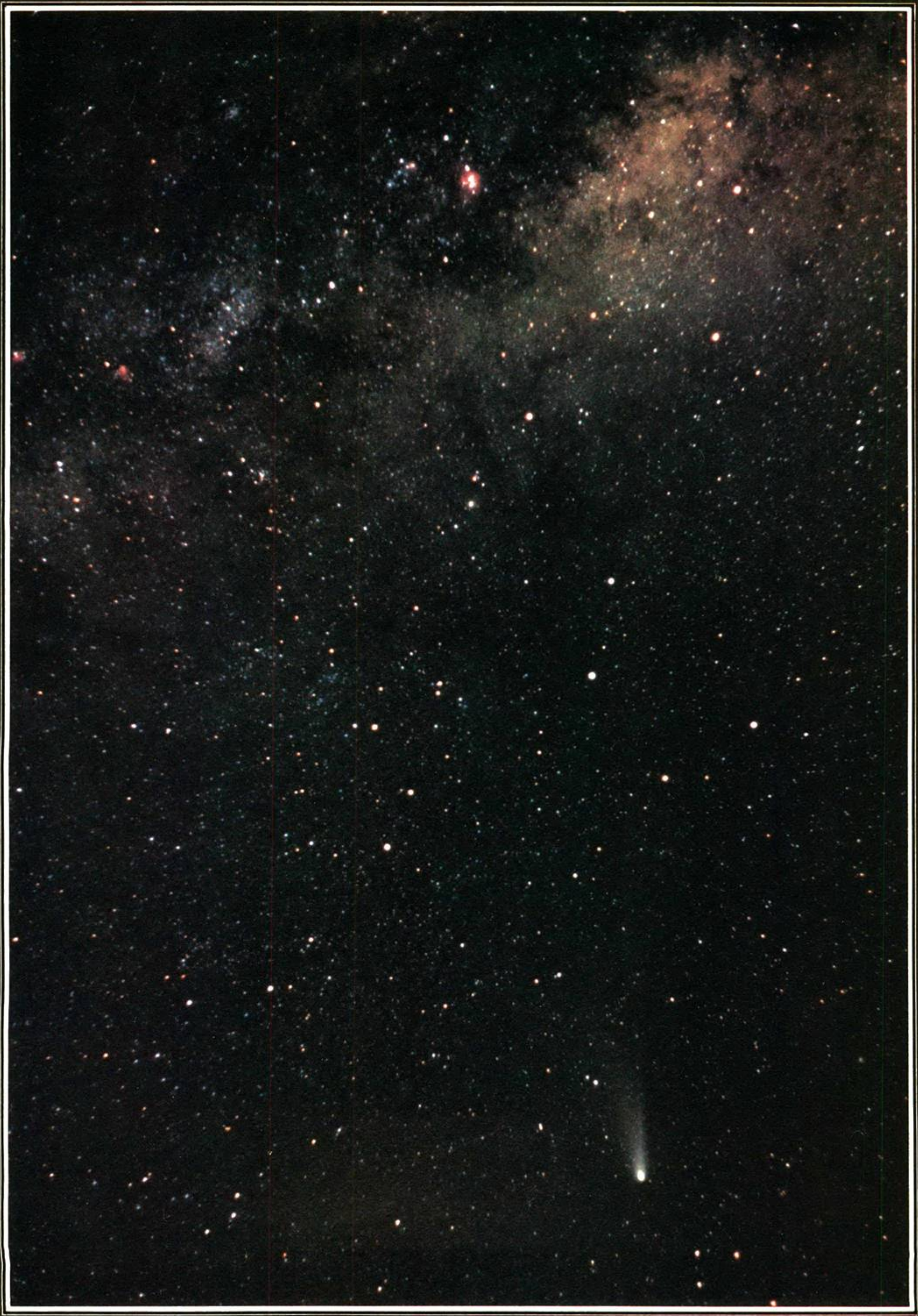
This book is one of a growing number of attempts to provide insight into physicists' new understanding of the evolution of the universe. Although written by an authoritative figure in the scientific community, readers should not be misled by the book's technical content. Although informed laypersons will probably not find the book challenging, newcomers to cosmology will be pleased to find a generally clear presentation of the recent advances in cosmology. Moreover, the discussion is adequately supported by background discussions of the concepts in physics and astronomy needed to appreciate the subject.

The opening chapter features a discussion of the failure of scientists to "communicate to the people . . . the meaning and importance, let alone the beauty and excitement of science." This provides a motivation and purpose for the book and lends credibility to the author as one who understands the general skepticism toward science and technology felt by much of the general public. This chapter also sets a precedent for the rest of the work by including many personal accounts of the author's experiences and insights from famous scientists of the past and present.

The next several chapters attempt to prepare readers who are unfamiliar with the concepts of physics. Included here are facts on astronomy, methods of physical measurement, quantum mechanical concepts, forces and fields, and the hierarchy of matter with emphasis on the quark theory. A section concerning the grand unification theories concludes the preparatory information, which encompasses two-thirds of the book. Although the author depends quite heavily on scientific notation to express the wide variety of scales involved in physics, a short appendix on the powers of ten is provided to rescue readers from confusion.

The subject of the book, the actual creation of matter, is treated in a single chapter. A cleverly devised "magic furnace" is used to clearly show how the constituents in a confined volume of space are expected to change with temperature. Armed with this knowledge, the author explains how asymmetries between matter and antimatter interactions, coupled with large deviations from thermal equilibrium, can act to generate residual matter from an initially "empty" furnace. Fritzsch then relates these concepts to observable phenomena and knowledge of the actual universe. Having laid exhaustive groundwork, the author treats readers to a reconstruction of the evolution of the universe from the primal explosion to the current epoch, including speculation about the fate of the cosmos.

The final three chapters constitute a loosely structured philosophical discourse with the suggestive titles "Unity and Diversity," "The Universe of the Mind," and "God and the Absurd Universe." Although a bit difficult to follow and probably best suited to someone familiar with the field, the discussion is thought-



Gazer's Gazette

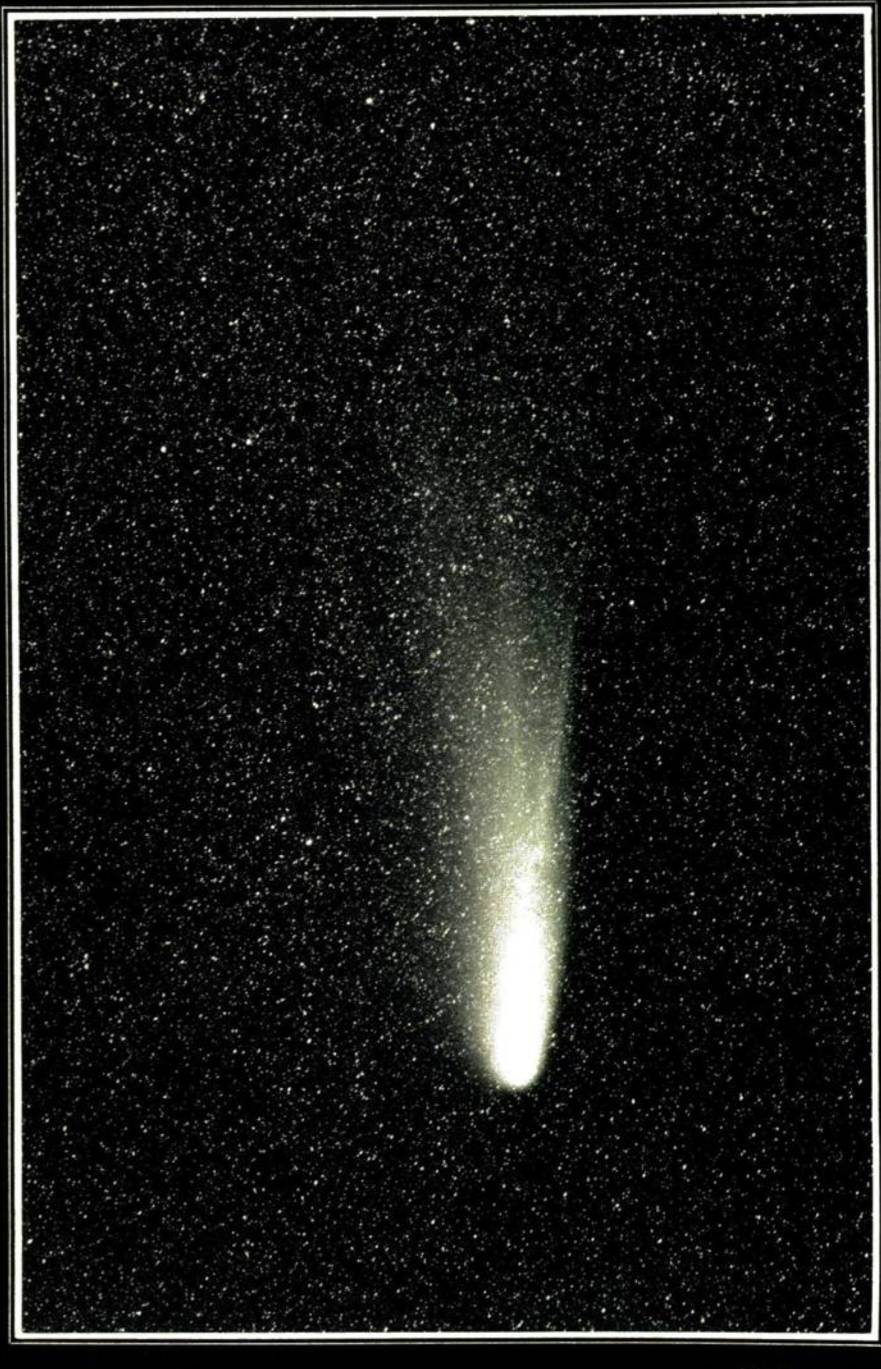
Halley Fades in Early April

As backyard astronomers all over the world peered at Halley's Comet during March, they had no idea that it would be their last opportunity to get a good view of the comet until 2061. The Moon increasingly interfered with Halley's morning sky show during the last half of the month, making the tail ever harder to spot.

And then came the unexpected. By the time Halley had moved into the evening sky early in April and the Moon ceased interfering, Halley had faded. The comet literally lost its tail, dramatically reducing its visibility in the process.

Optimism about Halley's appearance ran high throughout March. The comet was slightly brighter than most had predicted it would be, and early risers were treated to a wispy streak of gray light pointing upward toward the zenith. Binocular owners saw a bright nucleus attached to a detailed tail stretching over 8° long. Finally, Comet Halley was undisputedly the best comet since West in 1976.

During March, Halley lay very low on the horizon for Northern Hemisphere observers. To escape this problem, many residents of high latitudes traveled south where the comet appeared higher in the sky and could be viewed more success-



Right: On March 20, Halley's Comet lay in the rich starfields of Sagittarius and displayed a twin gas tail superimposed on a broad, fan-shaped dust tail. No one knew it at the time, but the comet had only two weeks of bright activity remaining. Photo by Al Lilge using a 6.9-inch f/3.5 refractor, 098-04 emulsion film, and a 15-minute exposure through a red filter.

Opposite page: This shot, taken on March 19, shows the comet poised below the summer Milky Way in Sagittarius. The Teapot asterism is at upper right; clusters and nebulae are scattered across the picture's upper half. Photo by Tim Pickering using a piggybacked 50mm f/2.0 lens, VR-400 film, and a 10-minute exposure.

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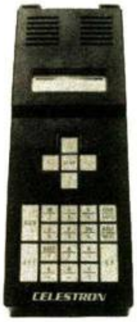

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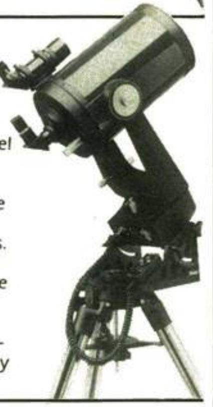

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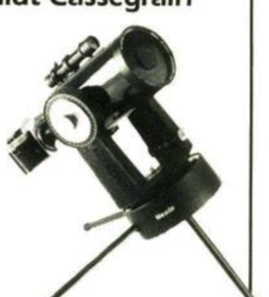

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Concluding with a useful glossary, the book should leave readers with a basic understanding of recent theories concerning the origin and evolution of the universe. Although not recommended for the informed layperson or scientist, someone new to the field with an interest in physics should find the book quite satisfying. *David Jourdan.*

The Life and Death of Stars
Donald A. Cooke
193 pages, hardcover, $29.95
Crown Publishers (1985)

Writing for the interested layman, the author — director of the Fels Planetarium in Philadelphia — provides a comprehensive, illustrated look at the types of stars and their evolution.

Space • Time • Infinity
James S. Trefil
255 pages, hardcover, $29.95
Pantheon (1985)

Written by a University of Virginia physicist and published in association with the Smithsonian Institution, this pictorial book is an overview of the universe as observed from Earth. The discussion is illustrated with over 300 photographs.

Ices in the Solar System
Jurgen Klinger, Daniel Benest, Audouin Dollfus, and Roman Smoluchowski, eds.
954 pages, hardcover, $99
Reidel (1985)

This is the proceedings of the NATO workshop on ices in the solar system that was held in Nice, France, in 1984. Discussed are the distribution and detection of ices in the solar system, cometary nuclei, ices on Mars, rings, icy satellites, and Pluto.

To Know the Stars:
A Simple Guide to the Night Sky
Guy Ottewell
41 pages, softcover, $7
Furman University (1984)

This book is designed mainly for children and teachers as an elementary guide to fundamental astronomy, the constellations, and the solar system. The contents include constellation maps for each month, descriptions of the ten prominent meteor showers and the twenty brightest stars, and information on observing with binoculars and telescopes.

Halley's Comet in History
F.R. Stephenson and C.B.F. Walker, eds.
64 pages, softcover, $8
British Museum Publications, Ltd. (1985)

This book was written to accompany an exhibition at the British Museum inspired by recently discovered Babylonian observations of Halley's Comet in 164 B.C. and 87 B.C. Chapters cover the Babylonian transliterations of day-to-day records, early Chinese observations, and an outline of Comet Halley's pre-telescopic period.

The Real Stuff
Joseph D. Atkinson, Jr. and Jay M. Shafritz
227 pages, softcover, $11.95
Praeger (1985)

The Real Stuff is the authorized history of NASA's astronaut recruitment and selection process. It examines the particulars of the selection of each astronaut group from the original Mercury Seven in 1961 to Shuttle Group X in 1984. The authors intend this to be the "complete" history on the evolution of the astronaut corps and the policies that guided its direction.

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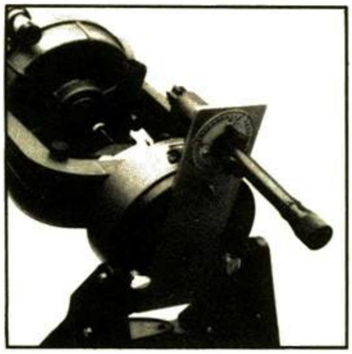

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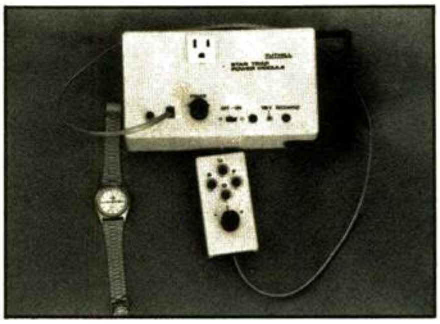

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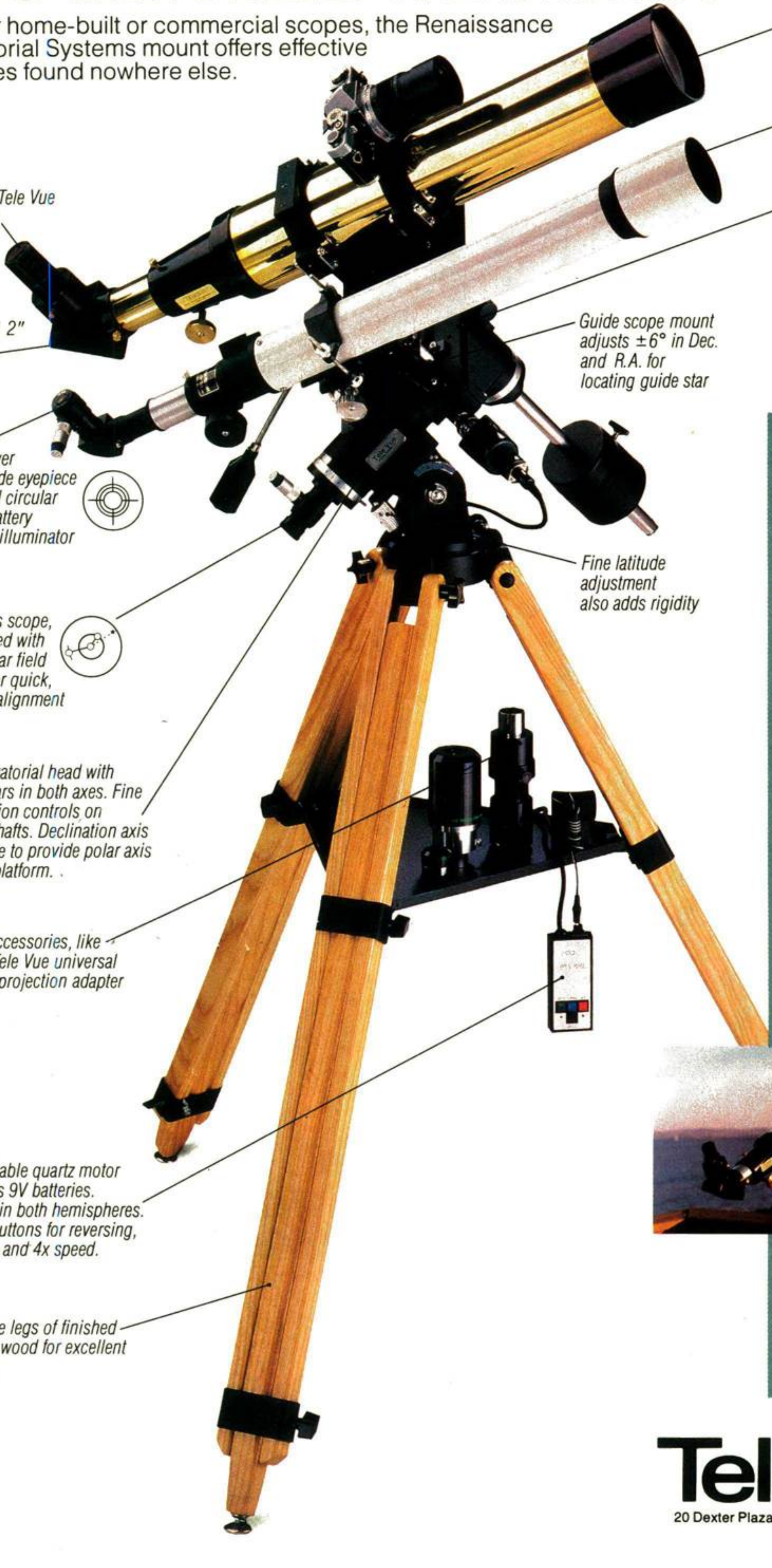

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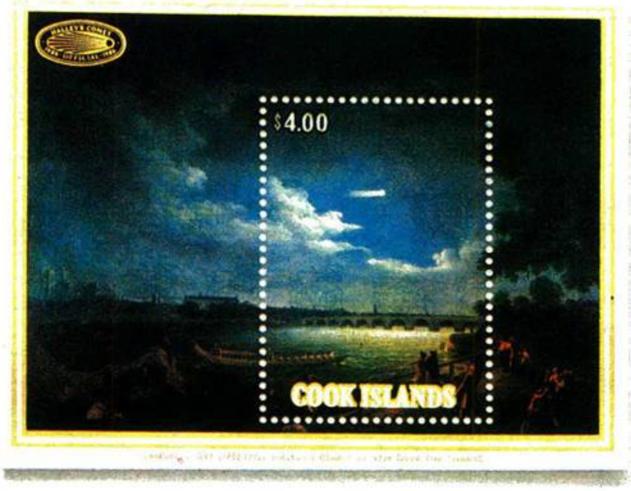
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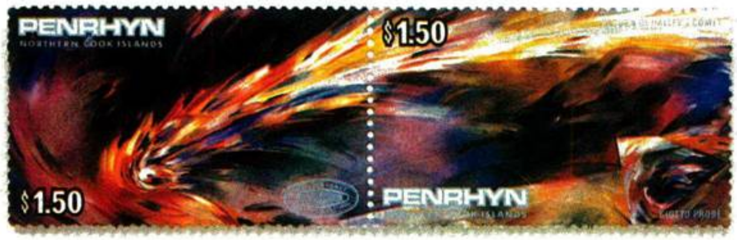
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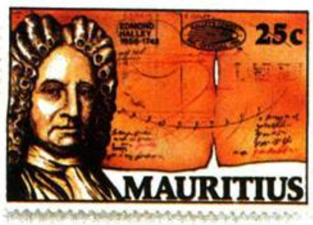
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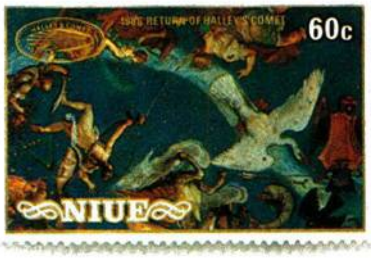
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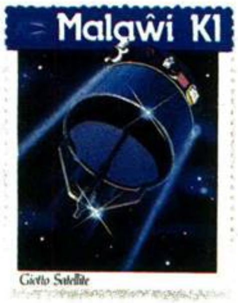
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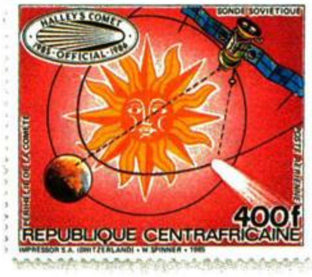
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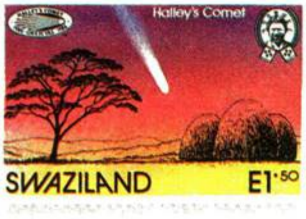
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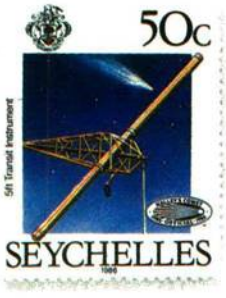
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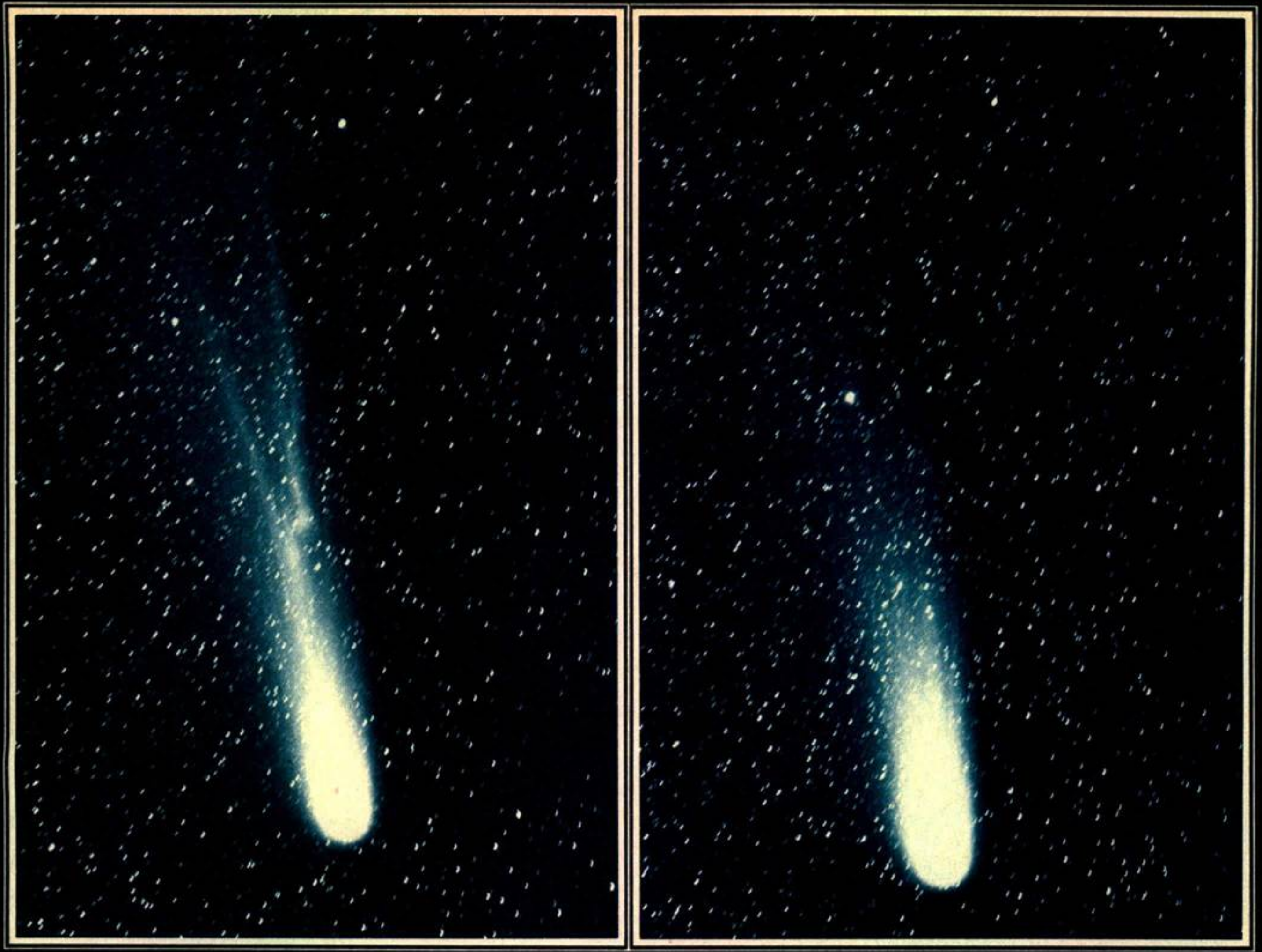


Opposite page: By March 22 the comet displayed a uniformly bright, wide dust tail lacking the sharp features of its gas tails. Photo by Steve Mathis using a piggybacked 200mm f/4 lens.

Top: Halley underwent a major "disconnection event" on March 21 during which its gas tail detached. On March 20 (left) the comet showed a sharply-defined, forked gas tail. The next evening (right) the gas tail was gone, leaving only a broom-shaped dust tail. Photos by Paul Roques using a 4-inch f/2.6 Schmidt camera, hypered Tech Pan film, and 30-minute exposures.

Above: On March 19, Chris Schur made this portrait of the rising comet by making 40-second exposures every 10 minutes.

fully. During the third week of March, Gary Becker and Susan Reisinger-Becker observed Halley from the tropical island of Aruba, some 90 miles north of the Venezuelan coast.

The Beckers described their expedition in *The Observer*, the journal of the Lehigh Valley Amateur Astronomical Society in Pennsylvania. "The nearly 30-degree change in latitude from the Lehigh Valley to Aruba made a considerable difference in [the comet's] appearance," they wrote.

Before leaving, Halley had been sighted as a fuzzy binocular object with a five-degree tail. From Aruba, they had seen it as an easy naked-eye target with a considerable (five to eight degree) tail. The onset of naked-eye visibility occurred when the comet was about five degrees above the horizon.

"As the week progressed, the tail increased in length and perceptibility, although telescopes and binoculars showed the coma and inner comatic structure becoming more and more diffuse. By 4:30 a.m., one could scan the convolutions of the Milky Way in Cygnus or Scorpius with the unaided eye, or look in the direction of Alpha and Beta Centauri and plainly see the comet in the same field of view. It was a marvelous experience not soon to be forgotten!"

Toward the end of March, the comet

was still bright enough to be successfully observed from the United States. On March 21, Tom Randall and friends observed the comet from Millbrook, New York: "We arrived at our viewing site at 3:50 a.m. and found the temperature to be 5° F with a slight wind blowing. A few seconds later I spotted Halley approximately 5° above the horizon using my 8x40 binoculars. The comet appeared fairly bright with the tail about half as bright as the coma. As minutes passed, the tail appeared brighter and longer, becoming quite easy to see with averted vision about 4:15 a.m.

"Halley lay two or three degrees east of the Teapot's handle. To the naked eye it appeared as bright as the Orion Nebula. Although many have stated that the view from 40° north latitude would be less than favorable, our location some 80 miles north of New York City offered a much better view than originally predicted. To say the least, Halley is giving us one hell of a show!"

Tom Hunt, ASTRONOMY's art director, observed Halley on March 26 from Racine, Wisconsin, some 30 miles north of metropolitan Chicago. Later he recounted what happened: "Having set out an Astroscan and other observing aids earlier, I walked out to my observing site guided by light from the setting Moon at 4:00 a.m. The sky didn't look good; a low haze showed the sweeping beam of a local airport searchlight some four miles away, but I was determined to see the comet. Since only the head of Scorpius was visible to the south, I knew my work was cut out for me.

"I started scanning the southern horizon with the Astroscan but nothing was visible through the thick haze, so I viewed other targets such as the Double Double in Lyra. By about 4:45 a.m. the southern horizon had cleared somewhat and I finally spotted Halley. It was small and the remaining haze made everything but the coma invisible.

"Because of the haze Halley appeared very similar to the first time I saw it, back in the fall," Hunt continued. "On that night, Robert Burnham, Bruce Bond, and I spied Halley using the Astroscan and binoculars. When my six-year-old son Brian first saw the comet he yelped, 'Yahoo!,' and ran into the house to tell the guests that Halley was 'just a smudge, but a great one!' My reaction on that chilly March morning was the same: the comet certainly wasn't impressive, but I was mighty glad to have seen it."

On March 29, Michael J. Hutchinson viewed Comet Halley from Longmont, Colorado. He wrote: "At 4:40 a.m. Mountain Standard Time I finally saw the faint glow of Halley's Comet in 7x50 binoculars. It lay low in the south-southeastern sky. Haze, moonlight, and light pollution on the horizon made the comet far more difficult to see than it should have been. The following night I saw the comet from an altitude of 6,500 feet up in the mountains. It then looked much better in the 7x50s, despite the moonlight and the fact that astronomical twilight was beginning. I kept watching it until dawn interfered with it an hour later."

But, unknown to thousands of observers, moonlight, haze, and twilight were not the only factors reducing the comet's brightness. Halley was rapidly growing dimmer, a fact disappointingly confirmed early in April.

Brian Skiff of Lowell Observatory put it best: "Comet Halley's lost its tail." Apparently the comet had undergone a major "disconnection event" during the first few days of April. During such an event, the gas tail breaks off and separates from the comet's head. These are fairly common occurrences, except that after the April event the comet simply "turned off," dramatically reducing its output of gas and dust. So just when everyone expected Halley to shine brightest — during its closest approach to Earth on the evening of April 10 — Halley fizzled.

Skiff continued his description of Halley: "From Mars Hill in Flagstaff the comet appeared virtually circular with a hint of very faint nebulosity stretching outward where the tail was once clearly prominent. I stood and looked at the globular Omega Centauri, then looked over at Halley, then looked back at Omega. Their brightnesses were very similar; the only real difference between the two objects was that Halley appeared several times larger."

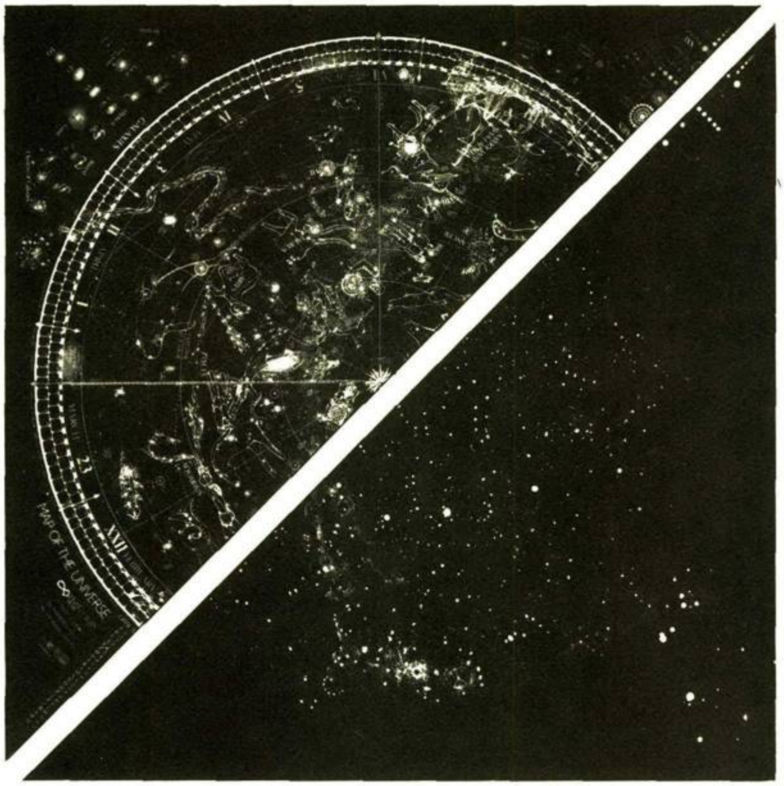
The timing of this rapid dimming was unfortunate, falling right when many excursions to the Southern Hemisphere were taking place. Greg Beach, vice president of the Sudbury Astronomy Club in Ontario, was on a special Air Canada flight to observe Halley on April 5, just about the time when the comet began rapidly fading. Beach described the comet as an "easy naked-eye object" from the aircraft. "The tail was traced with some difficulty to about 2°. In 10x50 binoculars the comet was easily seen with a tail that stretched just over half the field of view of the binoc's. Afterward, Air Canada provided a wonderful meal of filet mignon and French wine. We did the best we could and we're very happy!"

Although Halley's Comet clearly wasn't spectacular and fizzled long before most observers hoped it would, Greg Beach's closing sentiment is a fitting epitaph for the solar system's most famous chunk of sooty ice.

— *David J. Eicher*

Left: Halley was a bright, naked-eye object early in March when it had just moved into Sagittarius from Capricornus and was visible in the early morning sky. Chris Schur recorded this scene near Black Canyon City, Arizona, using a 50mm f/2.8 lens, Ektachrome 400 film, and a 4-minute exposure.

Below: On March 22, Halley passed within 3° of the giant globular M-55. Photo by Bob Webb using a 4-inch f/2.6 Schmidt camera, hypered Tech Pan film, and a 10-minute exposure. Courtesy Griffith Observatory.



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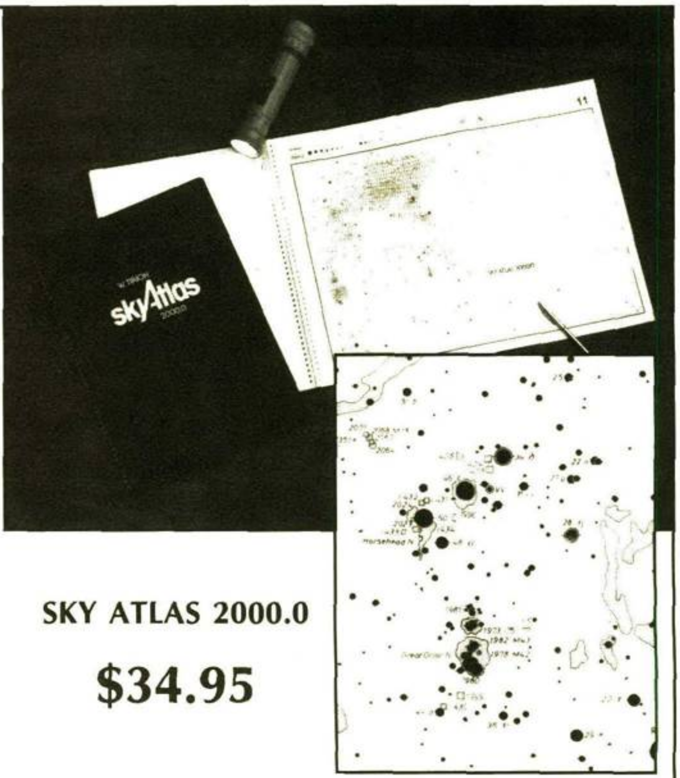

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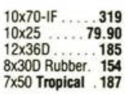

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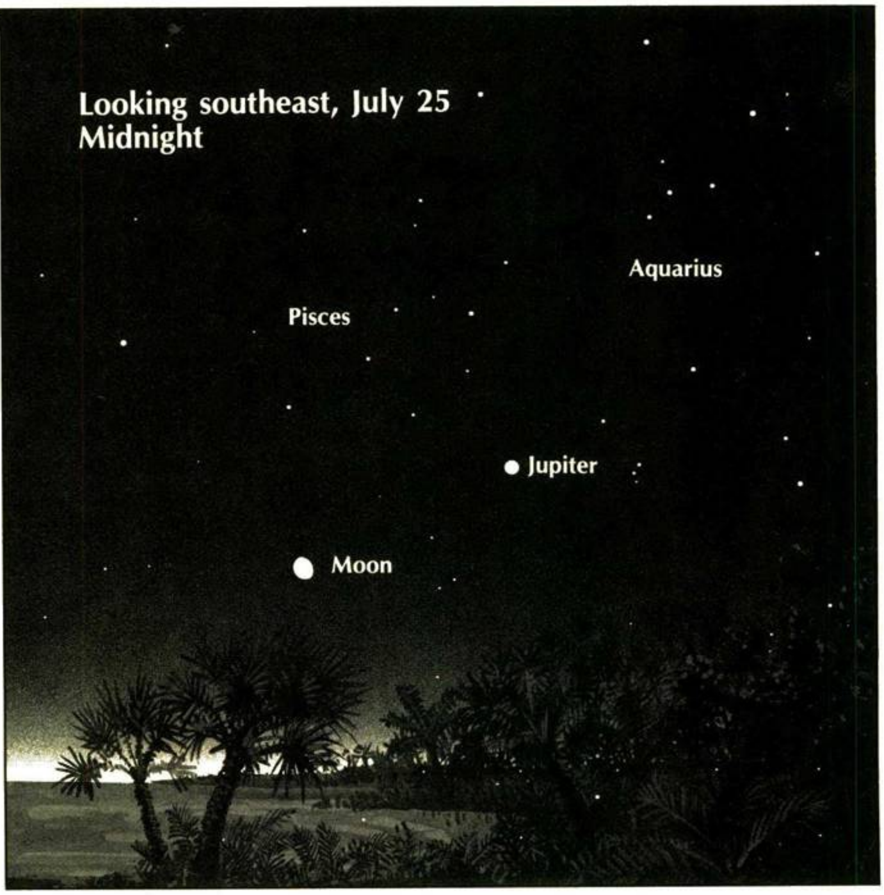
Mars Comes Closest to Earth

by Robert Burnham



The Wanderers

Nightfall comes late in July, with the sky not darkening fully until after 10 p.m. Nonetheless, many stars and planets become visible soon after sunset. The best place for skywatching is an open area, uncluttered with trees and houses, that's as far from streetlights as possible.

Venus is the bright "evening star" in the west after sunset. Shining brilliantly at magnitude −4, Venus is easy to spot despite being only 15° above the horizon in early dusk. (15° is about the width of a fist and three fingers held at arm's length.) On July 10, Venus will lie near the 1.4-magnitude star Regulus in the constellation Leo.

If you watch the pair for a week before and after the 10th using Regulus as a "sky marker," you can gauge Venus' motion against the stars. Motions like this, sometimes faster or slower, first led the skywatchers of antiquity to distinguish "the wanderers" (the planets) from fixed stars.

By the time full darkness arrives, another planet will be visible toward the south. This is **Saturn**, which lies among the stars of Scorpius. This constellation contains one bright star, Antares, that you may at first mistake for Saturn. Of the two, Antares is the one closer to the horizon. It is also a deeper orange color and is slightly dimmer (magnitude 0.9 to Saturn's 0.3).

Although Saturn appears to move relative to the stars, it orbits far from the Sun (10 times farther than Earth) and therefore moves only very slowly. Instead of seeing movement after a few days (as with Venus), you'll have to watch carefully for a week or two before Saturn's motion becomes evident.

As Saturn crosses the meridian in the south, **Mars** is the bright planet rising in the southeast. At magnitude −2.6, Mars looks like an amber jewel lying just east of the Teapot asterism in Sagittarius. Mars comes to opposition on July 10, meaning it lies 180° opposite the Sun in the sky. Opposition occurs when a planet that orbits the Sun beyond Earth is closest to us and shines brightest. (It's also when the planet appears largest in a telescope.) Mars, however, is a slight exception to the rule. Because its orbit isn't perfectly concentric with Earth's, Mars is actually closest to us on the 16th, one week after opposition.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

After Mars comes into view, you'll have to wait about two hours until you can spot the next of the naked-eye planets. **Jupiter** is among the stars of Aquarius and, at magnitude −2.7, far outshines them. If you compare the brightness and color of Mars and Jupiter, you'll find their magnitudes are almost identical, but Jupiter has a blazing white color distinctly different from Mars' amber hue.

And what about **Mercury**? It is visible for the first few days of July in the evening sky but is too low to be seen easily. On the 23rd, the planet passes between Earth and the Sun as it moves into the morning sky, where it will reach best visibility for the year in mid-August.

The **Delta Aquarid meteor shower** reaches peak activity during the predawn hours of July 28, but since this is also the date of Last Quarter Moon, you'll find that most of its 15 to 20 shower members per hour will be difficult to spot in the bright moonlit sky.

The shimmering stretch of Milky Way running through Cygnus is one of the summer sky's most distinctive features. To see it best, find a dark-sky site and observe when the night is clear and moonless. At left center in this photo is the ruddy North America Nebula, visible to unaided eyes as a fuzzy, roundish patch. Photograph by Charles Strickland.

The Starry Sky

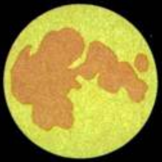
July and August evening skies feature some of the year's best celestial sights. The bright summer Milky Way arches across the sky while the Big Dipper, the familiar part of **Ursa Major**, slowly swings down to pass under the pole. Almost overhead lies the bright white star Vega in the constellation **Lyra** the Lyre, the legendary instrument that Orpheus played so well. Lyra is easily distinguishable as a compact group of pretty bright stars.

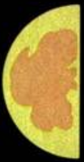
If you face east, you'll spot another bright star to the lower left of Vega. This is Deneb, the brightest star in **Cygnus** the Swan. Cygnus is also called the Northern Cross and forms a counterpart to the Southern Cross (Crux), which is visible only from south of about 25° north latitude. Although Cygnus lies in the star-crowded Milky Way, its long-necked form

July Night Sky

New Moon
July 7
12:55 a.m. EDT

First Quarter
July 14
4:10 p.m. EDT


Full Moon
July 21
6:40 a.m. EDT


Last Quarter
July 28
11:34 a.m. EDT

4th The Moon lies farthest from Earth at 4:02 a.m. EDT: 252,341 miles.

5th Earth is farthest from the Sun at 6 a.m. EDT: 94,766,000 miles.

7th New Moon occurs at 12:55 a.m. EDT.

10th Mars is at opposition today, though it will be closest to Earth on the 16th.

14th First Quarter Moon is at 4:10 p.m. EDT.

16th Mars is closest to Earth around 7 a.m. EDT: 37,500,000 miles.

17th The Moon passes about 5° south of Saturn.

18th A lunar occultation of Antares is visible over most of North America (see Backyard Astronomer for details).

19th The Moon is closest to Earth at 3:31 p.m. EDT: 224,220 miles.

20th The Moon will lie to the east of Mars tonight, having occulted it earlier as seen from eastern Asia.

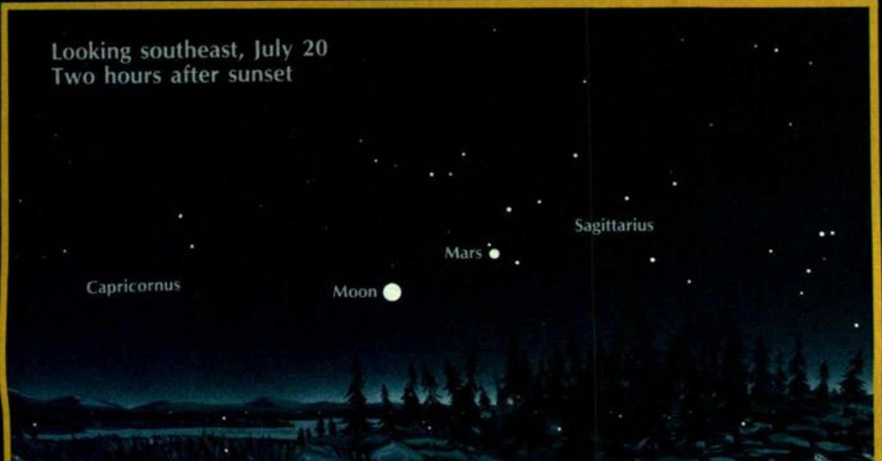
21st The Moon is Full at 6:40 a.m. EDT.

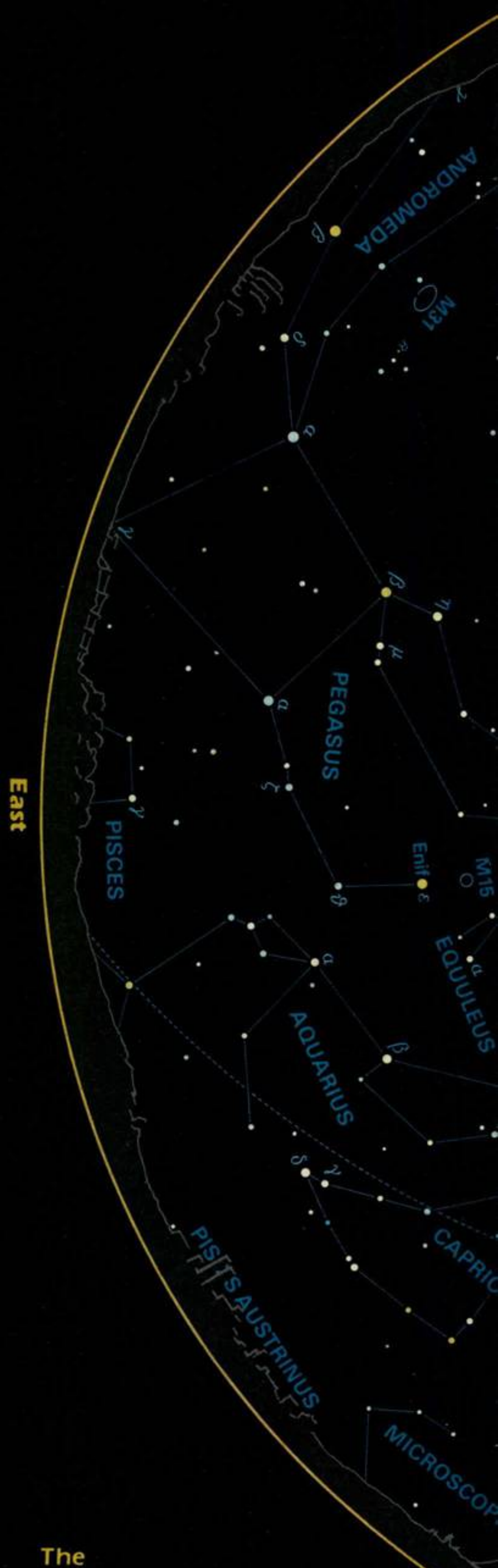
23rd Mercury passes through inferior conjunction, shifting from the evening to the morning sky. It will be at peak visibility low in the east in about three weeks.

25th The Moon passes a degree and a half south of Jupiter.

28th Last Quarter Moon occurs at 11:34 a.m. EDT. The Delta Aquarid meteors reach peak activity in the predawn sky, but bright moonlight will diminish their numbers to well below the 15 to 20 per hour that are normally visible.

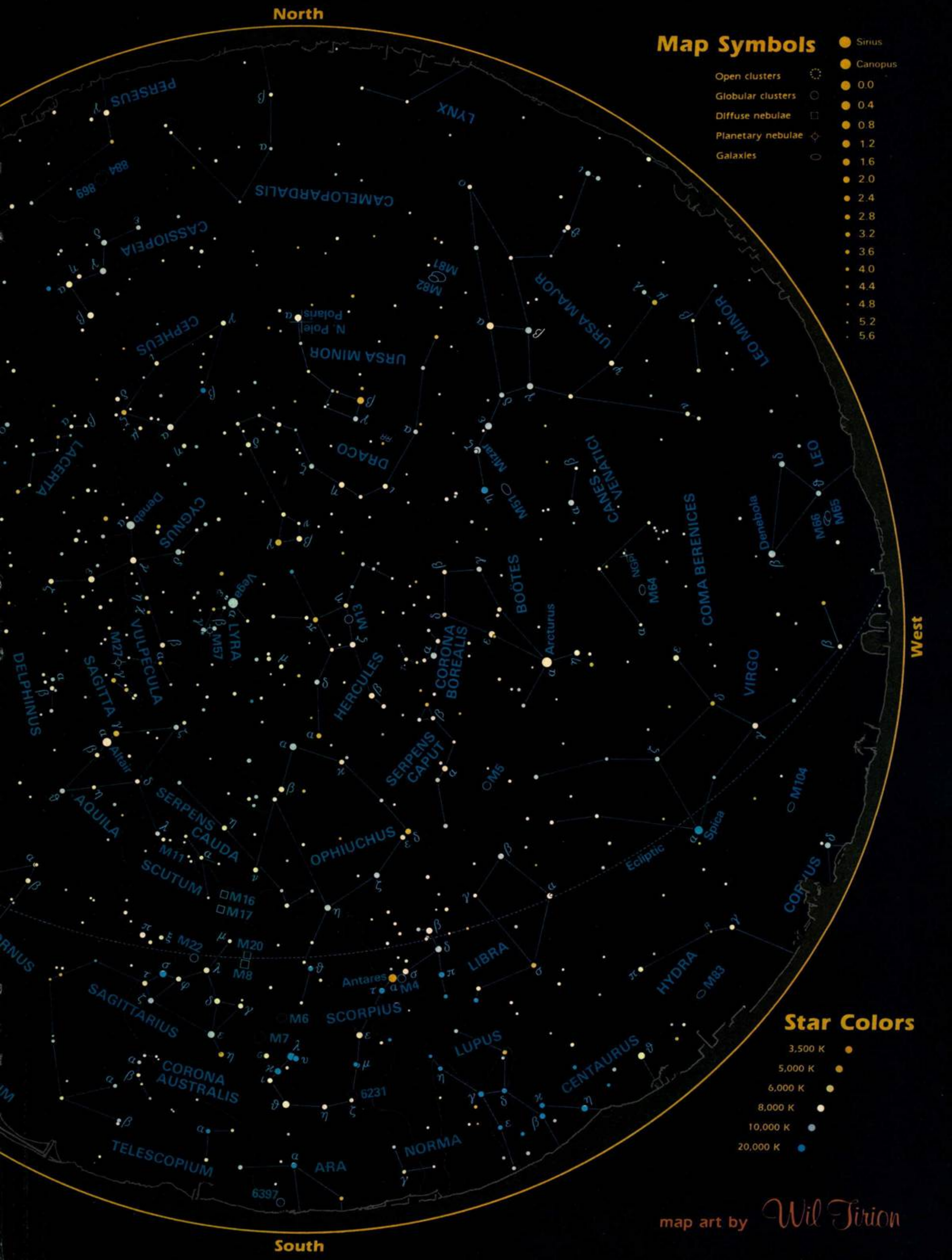
31st The Moon is at apogee for a second time this month at 5:20 p.m. EDT: 251,758 miles.


Looking southeast, July 20
Two hours after sunset
Sagittarius
Mars
Capricornus
Moon


ANDROMEDA
M31
PEGASUS
East
PISCES
Enif
M15
EQUULEUS
AQUARIUS
CAPRIC
PISCIS AUSTRINUS
MICROSCOP

The Star Dome shows how the sky looks at:

Midnight on July 1
11:00 p.m. on July 15
10:00 p.m. on July 31


North
South
West
Map Symbols
Open clusters
Globular clusters
Diffuse nebulae
Planetary nebulae
Galaxies
Sirius
Canopus
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
Star Colors
3,500 K
5,000 K
6,000 K
8,000 K
10,000 K
20,000 K
PERSEUS
LYNX
869
884
CAMELOPARDALIS
CASSIOPEIA
M81
M82
URSA MAJOR
LEO MINOR
Polaris
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CYGNUS
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M57
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M27
VULPECULA
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SERPENS CAPUT
M5
AQUILA
SERPENS CAUDA
M11
SCUTUM
OPHIUCHUS
M104
Spica
Ecliptic
CORVUS
M16
M17
M22
M20
M8
Antares
M4
LIBRA
HYDRA
M83
SAGITTARIUS
M6
SCORPIUS
M7
LUPUS
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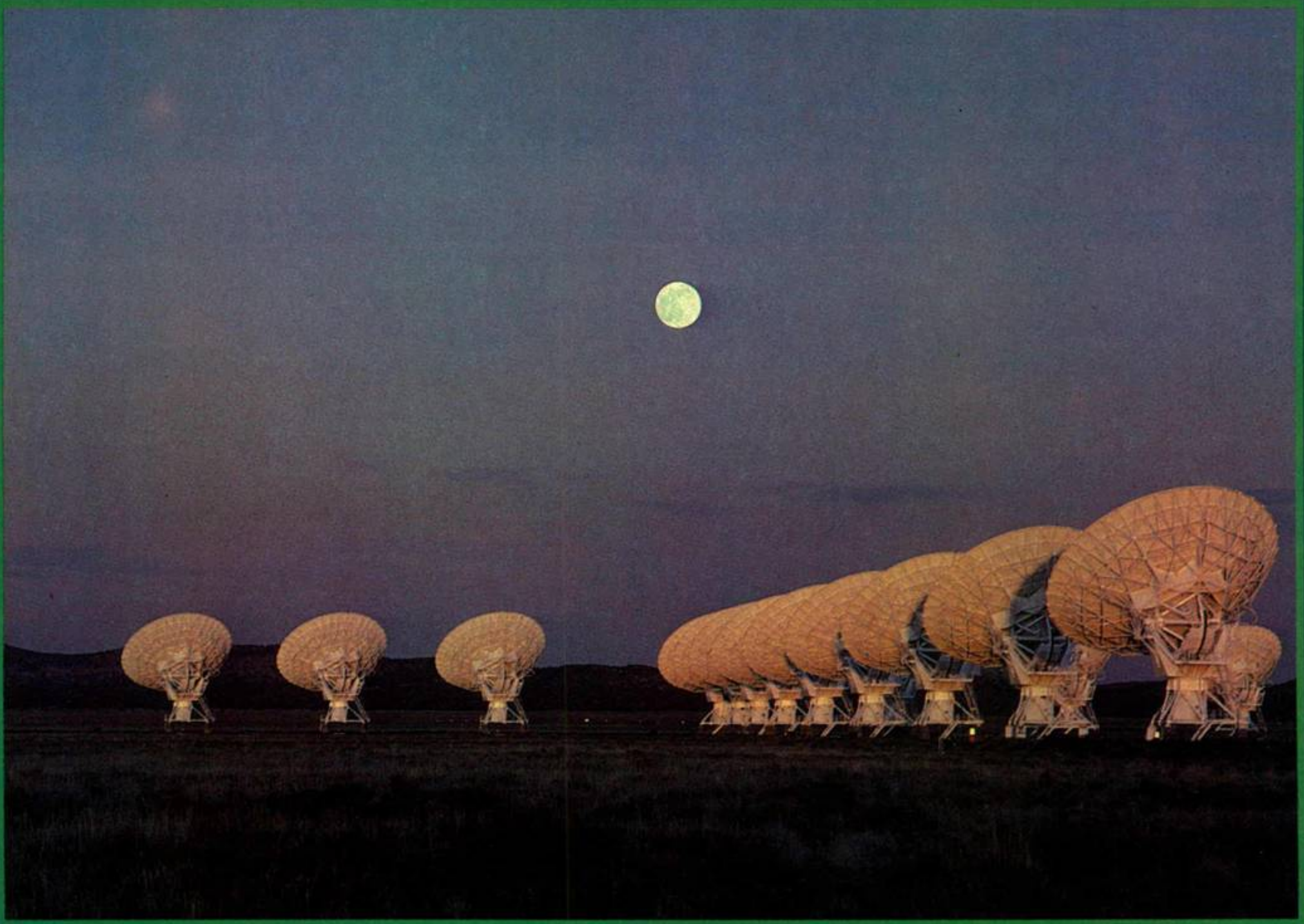
6231
TELESCOPIUM
ARA
NORMA
6397

map art by Wil Tirion



Top left: This January 1986 photo shows a Full Moon hanging high over the Very Large Array radio telescope near Socorro, New Mexico. Photograph by Barney Magrath.

Bottom left: In August 1984 this spectacular aurora was photographed from the South Pole Geological Station. Scorpius and Sagittarius lie "upside-down" in the photo, Jupiter lies below Sagittarius, Mars is near the head of Scorpius, and Saturn is at left center. Photo by Rick Dysan using a 15mm f/2.8 lens, 400 ISO film, and a 45-second exposure.

is easy to trace. Vega and Deneb team with a third bright star, Altair in **Aquila** the Eagle, to form a large, conspicuous asterism called **The Summer Triangle**.

Between Cygnus and Aquila lie two diminutive groups, **Sagitta** the Arrow (which is easy to spot and dates back to the Greeks) and **Vulpecula** the Little Fox (which is quite obscure). Vulpecula was created in 1690 by Johannes Hevelius and was originally named *Vulpecula cum Ansere*, the Fox with a Goose.

Continuing down the Milky Way toward the southern horizon, we first encounter **Scutum** the Shield (another of Hevelius' creations), and then, where the star clouds throng most densely, **Sagittarius** the Archer. The stars of Sagittarius are all 3rd magnitude or dimmer, but the **Teapot** asterism is easy to identify. Part of the Teapot has long been seen in another guise — that of the sky's third dipper. Do you see bright Mars? It lies just east of the so-called **Milk Dipper**, an asterism formed from Zeta (ζ), Tau (τ), Sigma (σ), Phi (ϕ), and Lambda (λ). Curled under Sagittarius is **Corona Australis** the Southern Crown, a fairly dim constellation that is distinct when viewed under a dark sky and without interference from trees and buildings.

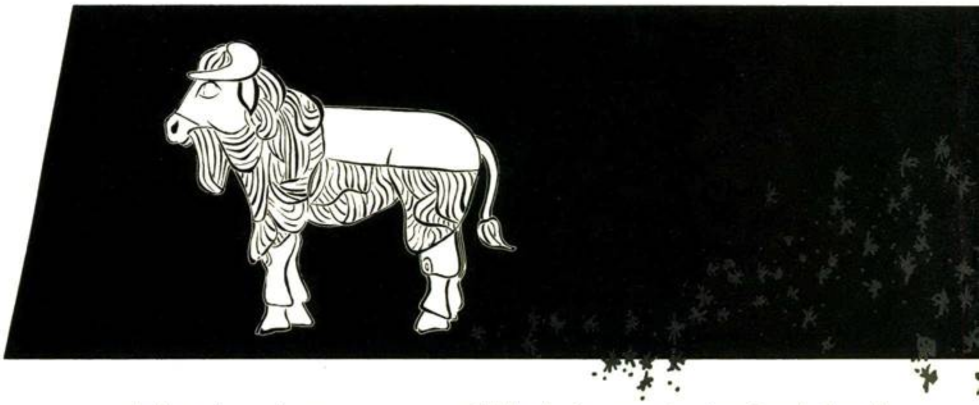
West of Sagittarius lies **Scorpius** the Scorpion, which currently harbors a planetary guest, Saturn. From Antares trace the Scorpion eastward, bending down and curving up again to reach its "stinger" at the star Shaula (λ). West of Antares, the insect's claws, formed by the three stars Beta (β), Delta (δ), and Pi (π), grasp for **Libra** the Scales, whose stars once belonged to the Scorpion.

The Archer and the Scorpion lie on the ecliptic, the invisible path of the Sun and planets. Westward from Scorpius, the ecliptic runs through Libra into **Virgo** the Virgin, now setting in the southwest with its bright luminary, Spica. Squeezed between the zodiac and the horizon, you'll see (depending on your latitude) **Lupus** the Wolf, **Centaurus** the Centaur, and a host of lesser constellations such as **Norma** the Carpenter's Level, **Ara** the Altar, and **Telescopium** the Telescope.

To finish this month's sky tour, let's return to the region high overhead and look to the west of Lyra. There stands **Hercules**, with his head toward the south, and the Keystone, which contains the globular cluster M-13 (use binoculars to view it). Below Hercules is a giant of a constellation, **Ophiuchus** the Serpent-Bearer. Ophiuchus' brightest star (Alpha [α] on the map) is named Rasalhague. The serpent Ophiuchus grasps lies in two pieces: its Tail (**Serpens Cauda**) runs east into the Milky Way and its Head (**Serpens Caput**) reaches over to grab **Corona Borealis** the Northern Crown — or perhaps to bite **Bootes** the Herdsman.

Skylore

Exactly when people first noticed that certain stars moved and others didn't is a mystery lost in time. Soon after this realization, early skywatchers also noted that the moving lights did not wander freely but were always found among a fixed set of star patterns, the same ones the Sun and Moon passed through each year.



In Mesopotamia dozens of centuries ago, ancient astronomer-astrologers looked at the sky and picked out six patterns (Taurus, Cancer, Virgo, Scorpius, Capricornus, and Pisces) in the stars among which the Sun and "wanderers" traveled. Since they were the home ground of the life-giving Sun, these patterns had a special mystical significance.

It appears that Taurus was the first to be identified, since the vernal equinox lay among its stars from about 3900 B.C. to 1700 B.C., when today's skylore was being created. We can imagine the people of those times noting where the Sun was as spring began, looking up at the V-shape of Aldebaran and the Hyades, and imagining a powerful, virile bull. Other animal shapes must have soon followed, for example, the Scorpion, which is a familiar denizen of arid lands.

Why there were only six constellations to begin with is unknown, but the scheme didn't last. In later antiquity, the natural division of the year into twelve "Moonths" demanded the Sun-track be similarly divided. By the time of the Greeks, these twelve star patterns were so well-established that they gave a name to the whole. Since the constellation figures all represented living things, the cycle of twelve was named the *zodiac*, from the Greek word for life. (Libra the Scales was invented by the Romans. Scorpius was considered a "double sign": the Scorpion proper, plus Claws, out of which Libra was created to honor Julius Caesar for his judicial fairness and calendar reform.)

For millennia, the zodiac has spawned a rich literature from the human consciousness. Its mythology is still vital to those who take astrology seriously. Every culture we know of has had myths regarding these constellations. The Akkadians called the zodiac the furrow of heaven that Taurus the celestial bull must plow each year. In some Christian legends the constellations stood for twelve significant events in Jesus' life or the twelve apostles. (Aries, for example, the constellation of the equinox 2,000 years ago, represented Peter.) For Buddhists, the zodiac represents the twelve stages in Siddhartha's career. Ancient Greeks found in them a memorial to the twelve labors of Hercules, with Leo standing for the Augean stables and Aries the Nemean lion.

Yet the zodiac also has concrete relevance to earthly affairs. As the Sun moved into each new group, the changing zodiacal signs served as a natural calendar to remind agricultural peoples of seasonal activities. For example, according to the Anglo-Saxons, in June (astrological Cancer) one was supposed to shear sheep and fell trees; in September (Libra) came winemaking; and in December (Capricornus) hog-slaughtering was done. Later, the English included falconing in May (Gemini). A similar yearly round of activities took place in most other countries as well.

Why does the zodiac and astrology continue to attract the general public so strongly today? Many answers could be given, but perhaps it's simply that the rational, physical universe is too big and too remote from human concerns for many people. The wonders that astronomers describe are awe-inspiring, no doubt, but their universe is a hostile, alien place. In the face of this, astrology — despite its lack of physical credibility — still offers many people a comforting, time-hallowed refuge from reason.

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Specify Lens Size	**H-Alpha**	**(MV)**
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52, 55, 58, 62mm	$45.00	$35.00
67, 72, 77mm	$52.00	$45.00
82mm	$55.00	

Hypered 2415 film, 36 exp ... $9.95 ... 3/$27

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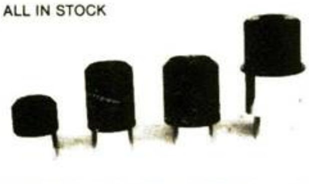

7.4, 10.4, 13, 17, 21, 26mm Plossl, 50°	$80
1.8x or 2.5x Tele Vue Barlow Lens	$80
32mm Plossl, widest true field in 1¼"	$95
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15mm Wide-Field, 1¼" eyepiece, 65°	$110
19mm Wide-Field, 1¼" eyepiece, 85°	$125
24mm Wide-Field, "superb", 65°	$140
32mm Wide-Field, 2" eyepiece, 65°	$210
40mm Wide-Field, "awesome", 65°	$265
4.8mm Nagler, 82° field	$140
7mm Nagler, 1¼" eyepiece, 82° field	$175
9mm Nagler, 82° field, "the best"	$210
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ULTRA HIGH CONTRAST

The **LUMICON UHC FILTER** is specially designed for visual astronomy in areas of severe light pollution or for viewing very faint nebulae at any location. **UHC** stands for **U**ltra **H**igh **C**ontrast and this filter is guaranteed to yield a higher visual contrast on planetary and emission nebulae than any other filter at any price. 24nm visible bandpass, 482-506nm.

"I CAN SEE THE OWL NEBULA!"
Tom Kramer saw the Owl Nebula, M-97, for the first time using a LUMICON UHC Filter. He stated, *"I had never seen M-97. . . I attached the UHC Filter and tried again. M-97 was right there. I could not believe it! The UHC Filter should be standard equipment."* **Tom Kramer, Sayville, NY**

For optimum astronomy, use either the **LUMICON DEEP-SKY Filter** or the **LUMICON UHC Filter**

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The **LUMICON DEEP-SKY FILTER** improves your view of **all** deep-sky objects including galaxies and comets. It removes natural and man-made light pollution and yields 3-6x contrast gain for nebulae and 1-3x contrast gain for clusters and galaxies. It is ideal for **both** visual use and B&W or color photography. This gentle filter yields the most natural view of any LPR filter available today. 90nm visible bandpass. 442-532nm. H-Alpha 656nm transmission = 80-95%.

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1¼" **LUMICON DEEP-SKY Filter** threads into most 1¼" eyepieces		$79.50
48mm LUMICON DEEP-SKY Filter (1.75" aperture), threads into most 2" eyepieces. Also fits LUMICON EASY-GUIDERS		$119.50
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1¼" **LUMICON UHC Filter** threads into most 1¼" eyepieces	$79.50	$99.50
48mm LUMICON UHC Filter (1.75" aperture) fits most 2" eyepieces	$159.50	$199.50
Set of Both 1¼" **DEEP-SKY** and **UHC Filters** (Save 11%)		$159.50
1¼" **H-BETA Line Filter** 9mm bandpass at 486nm). For the California Nebula, Horsehead Nebula, and other extremely faint nebulae)		$89.50
48mm "Horsehead Nebula" H-BETA Line Filter		$189.50
Oxygen-III Filter for very faint planetary and diffuse nebulae, 11nm bandpass at 496nm and 501nm 0-III lines	1¼" $99.50,	48mm $199.50
Telephoto lens adapter for 2" or 48mm filter. Select 46, 49, 52, 55, 58mm		$6.95
Universal adapter for 1¼" filters. Adapts the 1¼" filters to any 1¼" eyepiece		$16.00
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**Premium filters are selected best of the lot and typically have 5-10% higher transmission. Not always available. Include individually measured transmission data.*

DEEP-SKY ASTROPHOTOGRAPHY

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†Patent Pending

MODEL 100 HYPER-KIT for 35mm film, rolled-up. *Takes longer*, but it easy to use. Not recommended for 2415 .... **$225.00**

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All **LUMICON EASY-GUIDER™** off-axis guiders† have both radial and 360° rotational adjustments for 5X eaiser guide-star selection, use 48mm filters, 360° camera rotation, large prisms fo bright guide-starts. *Specify Camera and Telescope type.*
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Full aperture. Installs in secs. Specify 2" or 1¼".

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Illuminated reticle eyepiece system	$79.50

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For C-8, Meade 2080, Dynamax-8. Includes 50mm achromatic lens for f/5.8 operation-3X shorter exposures! **Superb rich field viewing, too!**
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Hasselblad adapter	$195.00

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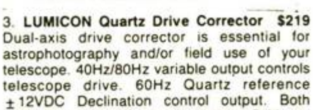
1. **Illuminated reticle eyepiece. . . $79.50** Lumicon 12mm eyepiece system has adjustible L.E.D. illumiation, dual crosslines, battery pack.
2. Cable release for long exposures. **$9.95**

3. **LUMICON Quartz Drive Corrector $219** Dual-axis drive corrector is essential for astrophotography and/or field use of your telescope. 40Hz/80Hz variable output controls telescope drive. 60Hz Quartz reference ± 12VDC Declination control output. Both 110VAC and 12VDC input for home or field use. Declination reverse switch for Newtonians.

Declination motor (state telescope) .. $60
NEW Deluxe Digital Qtz. Drive Correc. **$298**



HYPERSENSITIZED FILM

LUMICON Hypersensitized film is essential for good deep-sky astrophotography. Deduct 10% for 3 or more rolls (mixed o.k.).

Film Type, 35mm	**Exposures**	**Price**
2415, Ultra-fine B&W, red sens.	36	$9.95
SR1600, fastest of all, color negs	24	$12.95
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Ektachrome 200, fine grain slide	24	$12.95
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MEADE 2080/LX3 .... $1695

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Multi-coated silvered optics, boost trans. 18% ... **add $149**
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NEW! Quartz Drive Meade 2080/LX3

The Meade 2080/LX3 with built-in quartz electronic drive system is positively the highest performance 8" Schmidt-Cassegrain telescope system available today.

FEATURES OF THE MEADE 2080/LX3

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★ Built-in quartz microelectronic sidereal drive system
★ 8x50mm right-angle illuminated Polar viewfinder
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★ 25 ft. cord for field operation from a 12V car battery
★ 25 ft. cord w/converter for 110VAC 50/60Hz operation
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★ Piggyback camera mount for effortless wide-field photography **(Best to photograph Comet Halley!)**
★ Audio cassette explains features, set-up, visual & photographic applications
★ Lifetime warranty on telescope, wedge, tripod
★ 8" f/10 Schmidt-Cassegrain optics, F = 2000mm
★ 20mm Research-Grade Erfle 1¼" eyepiece (100X)
★ 7mm Research-Grade Orthoscopic eyepiece (286X)
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★ Ultraprecision 6" LX worm gear motor drive
★ Oversize 8.25" primary mirror benefits photography
★ Convenient fork mount with slow motion controls
★ Best overall mechanical stability of any 8" Cassegrain
★ Large right ascension & declination setting circles
★ Padded carrying case
★ Eyepiece rack
★ Latitude scale and no-tool knob set
★ Adjustable height heavy duty tripod with eyepiece rack
★ Dew shield & accessory tray, optional **add $88**
★ Star map & finder cards for Messier objects
★ Red astronomer's night flashlight
★ **Optional:** Multi-coated/silvered optics boost transmission 18%, **add $149**

2120/LX3 10" System $2495

The 10" Meade 2120/LX3 collects 56% more light than an 8" telescope for significantly improved viewing and astrophotography. It has all the features of the 2080/LX3 (see above.)

Meade 2120/LX3 w/wedge & tripod ($5000 list) **$2495**
Multi-coated silvered optics boosts transmission 18%.
Highly recommended! ($290 list) **$195**
#710 dew shield (10") Essential! ($140 list) **$98**
#36 dual-axis drive corrector control box ($150 list) **$99**
#38 declination motor and clutch ($150 list) **$99**
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f/4-f/10 operation (state camera) **$395**

NEW! 2080/GEM and 2120/GEM

Schmidt-Cassegrain Optics on German Equatorial Mount

2080/GEM, 8" f/10 w/equatorial mount ($2100 list) ... **$1150**
Multi-coated silvered optics, boost transmission 18% **add $149**
2120/GEM, 10" f/10 w/equatorial mount **and with multi-coated silvered optics** ($4300 list) **$2295**
Dew shield & accessory tray, 8" .... **$72** 10" **$144**
#785 motor and quartz drive correc. system ($270 list) **$198**
#3000 computer control system ($1500 list) ..... **add $895**

The Meade 2080/GEM and 2120/GEM telescopes include the same diffraction limited optics as the 2080/2120/LX3. Large, stable German equatorial mount with setting circles, slow motion controls on both axes, large 8X50mm finderscope, 25mm 1¼" eyepiece, integrated polar alignment scope, and heavy duty adjustable height tripod (hardwood for 2080, metal for 2120). The computer control provides automatic object location from an extensive software library of deep-sky objects.

4" MEADE 2045 w/table tripod $695

NEW! Meade 2045/LX3 w/quartz drive **$885**

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2045/LX3
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Meade Model 2045 — Advanced engineering and superb optical performance in a beautiful ultraportable system.

FEATURES OF THE MEADE 2045

★ 4" f/10 Schmidt-Cassegrain optics, F=1000mm
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★ **LX3:** quartz-controlled elec. drive, 12VDC or 110VAC input
★ High transmission coatings on front corrector lens
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★ 1¼" 25mm (40X) and 9mm (111X) eyepieces
★ Fork mount with setting circles, manual slow motion

HIGHLY RECOMMENDED OPTIONS

Model 43 drive corrector uses 12VDC ($120 list) **$96**
See Meade 2080/LX3 options
Wedge & field tripod as for 2080/LX3 ($470 list) **$298**
Dew shield ($70) ..... **$49** Solar Filter ($180) **$139**

OPTIONS BOOST PERFORMANCE

LUMICON UHC Filter for nebulae. Standard 1¼" **$79**
Prem 1¼", **$99;** Std 48mm, **$159.50;** Prem 48mm, **$199.50**
LUMICON Deep-Sky Filter, 1¼" Premium **$79**
48mm Prem Deep-Sky ..... **$119.50, $99.95** w/Easy-Guider
Adapter for viewing w/1¼" eyepiece **$20**
Dust covers. Keep optics clean. For 6" **$16/pair**
8" .... **$20/pair;** 10" .... **$18;** 16" **$24**
LUMICON Rich-Field Viewer (2080) **$140**
LUMICON Newtonian Easy-Guider, 1¼" or 2" **$169**
#122 2X Barlow ($60 list) **$48**
Dual-axis drive corr. and elec. dec. for 2080/LX2 .. **$298**
for model 628, 826, DS-10 .... **$340** for DS-16 .... **$440**
Tele Vue 32mm Plossl 1¼" eyepiece **$88**
LUMICON Cassegrain EASY-GUIDER for 2080/LX2 & LX/3
(state camera) **$225**
Illuminated reticle eyepiece & battery pack **$79.50**

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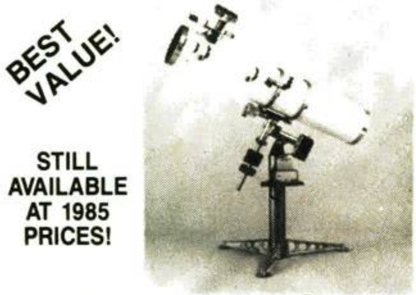
8" f/6 NEWTONIAN.........$995



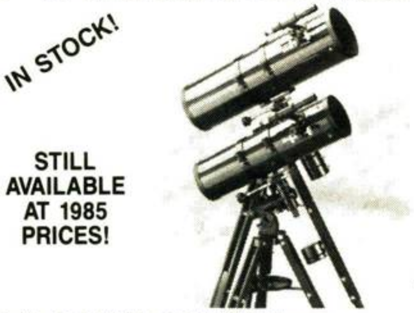
Model 826, 8" f/6 Telescope w/accessories

Model 628, 6" f/8 with motor drive ($1220 list)......... **$785**
Model 628C, 628 w/2" focuser, 8x50mm finder ($1450 . **$865**
Model 826C, 8" f/6 with motor drive, #680 2" focuser and 8x50mm finderscope ($1590 list).................. **$995**
—Collects 78% more light than a 6" telescope.

These Meade Deluxe Series reflecting Telescopes have superb image quality at low or high power. They include an equatorial mount with motor drive, pier, legs, setting circles, 2" rack & pinion focuser, 8X50 finderscope (628C & 826C only), 25mm (48X) and 9mm (135X) 1¼" eyepieces, altitude and azimuth fine adjustments for polar alignment.

#43 drive corrector uses 12VDC ($120 list)............ **$96**
#47M Dual-axis drive corrector & elec. dec........... **$340**
1¼" or 2" EASY-GUIDER (state camera)............ **$169**

6" f/5 NEWTONIAN........$695



Models 6600 (6" f/5) & **8800** (8" f/4.5) telescopes
Model 6600, 6" f/5 Newtonian telescopes ($1300 list) . . **$695**
—Best performance & value; bright, wide views.
Model 8800, 8" f/4.5 Newtonian Telescopes ($1700) . . . **$895**
—Collects 78% more light than a 6" telescope.

These meade Professional Series reflecting telescopes yield superb rich-field viewing w/bright images. They include an equatorial mount w/adjustable tripod, setting circles, slow motion controls, 6x30mm view-finder, 1¼" focuser, 25mm & 9mm 1¼" eyepieces & accessory tray.

#784 Quartz motor & quartz drive corrector ($270 list) . . **$198**
Basic camera adapter (for moon & planets)........... **$32**
1¼" LUMICON Easy-Guider (state camera)........... **$169**

16" f/4.5 NEWTONIAN......$1995

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Meade DS-16A with Accessories

The DS Series of 10" and 16" reflecting telescopes are ideal for deep-sky viewing and photography.

DS-10A, 10" f/4.5 with motor drive ($1600 list)......... **$995**
—Gathers 56% more light than an 8" telescope
DS-16A, 16" f/4.5 with motor drive ($3140 list)......... **$1995**
Sealmaster ball bearings, highly recommended . . . **add $229**
—Gathers 400% more light than an 8" telescope

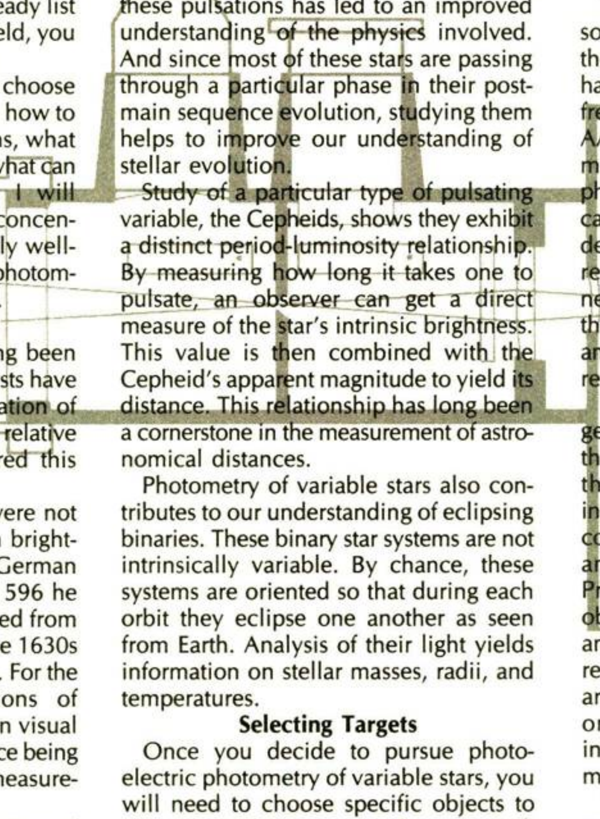
Both the DS-10A and DS-16A telescopes include an equatorial mount, #680 2" focuser, motor drive, setting circles and 25mm 1¼" eyepieces. The DS-10A is shipped freight collect.

6x30mm finderscope with brackets ($56 list)........... **$42**
8x50mm finderscope with brackets ($130 list)........... **$96**

Equipment Atlas

Photometry of Variable Stars and Asteroids

by
Frank J. Melillo



In last month's issue I focused on the preliminary steps necessary to carry out photoelectric photometry. These measurements can be scientifically valuable and are quite easy for amateurs to perform in their own backyards. The equipment is available at a reasonable cost and is simple to operate. With a ready list of references to help you in this field, you should be set to start observing.

Now you need to know how to choose individual targets for observation, how to make the appropriate observations, what to do with the resulting data, and what can be learned from these studies. I will answer these questions while concentrating on two subjects particularly well-suited for backyard photoelectric photometry: variable stars and asteroids.

Variable Stars

Variable star observing has long been an area where amateur photometrists have contributed greatly. The combination of vast numbers of variables with the relative ease of measurement has fostered this tradition.

The first indication that stars were not immutable but actually varied in brightness came from the work of German astronomer David Fabricius. In 1596 he observed that the star Mira dimmed from 3rd magnitude to invisibility; by the 1630s its periodic nature was discovered. For the next few centuries, observations of variable stars necessarily relied on visual photometry, the only major advance being the telescope which allowed measurement of fainter stars.

In 1911 the American Association of Variable Star Observers (AAVSO) was founded to systematically collect visual observations of variable stars. Since then, amateurs have submitted millions of reports. The AAVSO has more recently formed a section dealing exclusively with photoelectric photometry. Because many of the stars in the AAVSO program are difficult to measure visually, those doing photoelectric work can contribute valuable information on variable stars.

What can you find out through photometry of variable stars? The majority of stars exhibiting variability do so because they are pulsating. As they alternately expand and contract, their temperatures also vary. A variable generally reaches maximum brightness when it is at its hottest. The analysis of these pulsations has led to an improved understanding of the physics involved. And since most of these stars are passing through a particular phase in their post-main sequence evolution, studying them helps to improve our understanding of stellar evolution.

Study of a particular type of pulsating variable, the Cepheids, shows they exhibit a distinct period-luminosity relationship. By measuring how long it takes one to pulsate, an observer can get a direct measure of the star's intrinsic brightness. This value is then combined with the Cepheid's apparent magnitude to yield its distance. This relationship has long been a cornerstone in the measurement of astronomical distances.

Photometry of variable stars also contributes to our understanding of eclipsing binaries. These binary star systems are not intrinsically variable. By chance, these systems are oriented so that during each orbit they eclipse one another as seen from Earth. Analysis of their light yields information on stellar masses, radii, and temperatures.

Selecting Targets

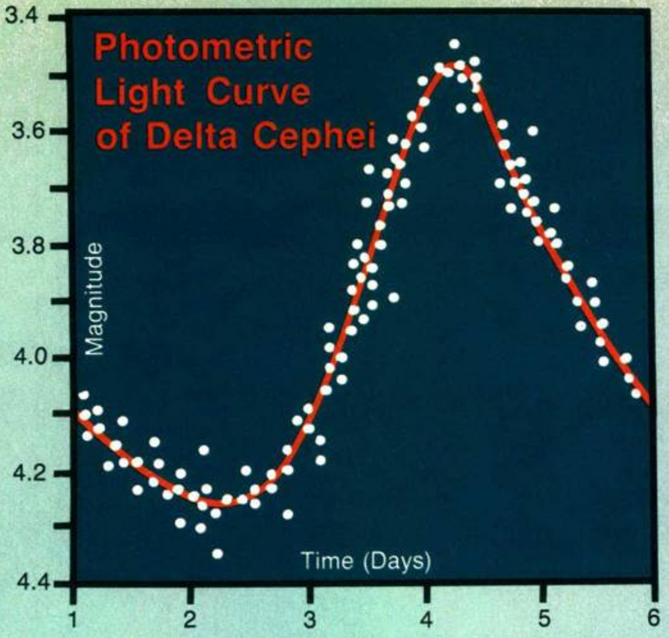
Once you decide to pursue photoelectric photometry of variable stars, you will need to choose specific objects to observe. With thousands of stars to pick from, some of which have already been well studied, how do you establish a viable observing program?

Perhaps the easiest way to begin is by joining one of the organizations specializing in this type of work. Both the AAVSO and the International Amateur-Professional Photoelectric Photometry (IAPPP) association are helpful in this regard. The AAVSO has a special photoelectric photometry program to observe sixty-five variables of magnitude 8.5 or brighter. If you are interested in this approach, simply write and tell them that you want to make photoelectric observations. Include in your letter the kind of observing experience you have, the type of telescope and photometer you'll be using, and where you live.

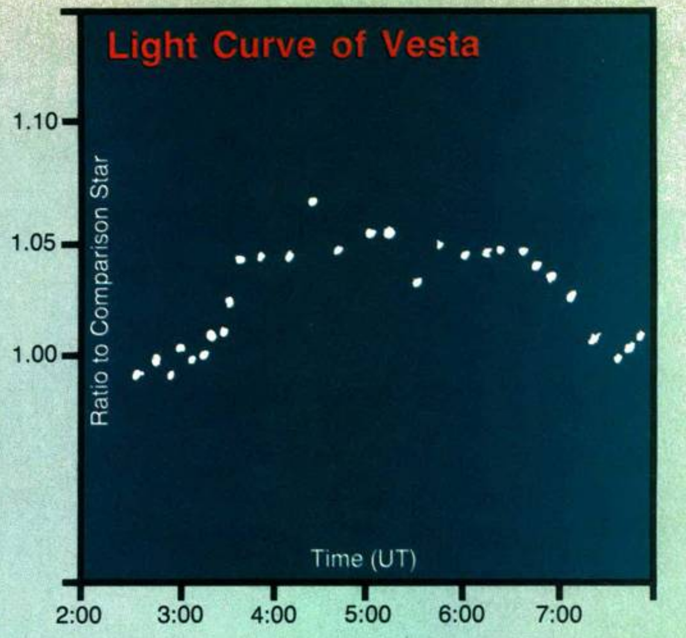
The AAVSO will initially assign you some specific stars to observe based on the information you provide. Once you have gained some experience, you will be free to choose your own variables. The AAVSO also has several special committees dealing with various aspects of photoelectric photometry from whom you can get information and advice. If you decide to become a member, you'll receive a photoelectric photometry newsletter once every three months or so that provides information on events, amateur activities, and special observation requests from professionals.

The IAPPP does not have a program geared specifically to new observers, but the journal you receive as a member lists their future symposia, which are informative for beginners. The journal also contains suggested observing programs and the contact people for them. Professional astronomers often request observations of stars through the IAPPP, and these programs can be personally rewarding. (See "Epsilon Aurigae," February 1986.) The IAPPP is a member-oriented group, willing to answer individual questions on any problem you may have.

There are three main categories of variable stars — pulsating, eruptive, and eclipsing — with dozens of subclasses. In the end it's your decision whether to concentrate on one type of variable or work on several different types at once. If you want to contribute meaningful data, though, make sure that your choices have not already been heavily observed. This can be one of the biggest benefits of belonging to a variable star organization: the stars they want studied are chosen by professionals to be of special importance and in need of research. These stars may



The final step in most photoelectric observations is the production of a light curve. Shown here are the raw data points and a smooth curve averaging the observations of the prototype Cepheid variable Delta Cephei. This variable star has a period of about 5.4 days and an amplitude of 0.7 magnitudes.



Raw observations of the asteroid 4 Vesta show that it varies in brightness despite being nearly spherical. These changes are due to light and dark regions on the asteroid's surface. This light curve shows that Vesta has a rotational period of 5 hours and 20 minutes and an amplitude of 0.12 magnitudes.

have unknown or irregular periods, they may have inadequate data collected, or they may even be of an unknown class.

Once you have decided on the variables you want to monitor, there are still a few more things to consider. First, the star has to be within the range of your telescope at minimum light as well as maximum. (This is where a larger aperture is advantageous.) Another consideration is the period of the star. If you choose a long-period variable, your observations will have to stretch over several months or longer. If you go this route, it is best to choose a star that will be above the horizon for an extended period at times you can observe.

The Observing Process

Once you have a list of specific variables in your observing program, the AAVSO can supply you with finder charts for those stars at a small cost. At the top of each chart is the variable's location, type, a few of its characteristics, and a comparison and check star. The variable has an arrow pointing to it and the comparison and check stars are indicated by word and pointer.

The first steps on an observing night are to uncap your telescope, so it reaches equilibrium with the outside air temperature, and turn on all the electronics at least an hour before starting to observe so that the electronics and photomultiplier tube can stabilize.

Once your telescope is set and you have the correct finder charts in hand, you're ready for the night's observing. The easiest and most accurate method to use is differential photometry, where you compare the light from your program star to that of a nearby comparison star. Instead of measuring the absolute brightness of the variable star, you are measuring the difference between the variable and the comparison star.

At the telescope you will normally take readings of the sky brightness, a comparison star, and the variable star. A few times a night you will also want to measure the check star. Use the previewer eyepiece to center the object in your field of view, then use the postviewer to make sure it is centered in the diaphragm. Choose a diaphragm that allows as little excess light to enter the photometer as possible without excluding any of the target's light.

When a star is measured in this way, some of the sky brightness will inevitably enter the photometer. The problem is exacerbated under light-polluted skies or when the Moon is out. However, by taking a sky reading and a stellar reading using the same-sized diaphragm and subtracting the sky reading from the stellar, you effectively cancel out the sky brightness from the stellar reading and arrive at the stellar brightness.

A typical sequence of observations for a variable star might be: 1) sky, 2) comparison star, 3) variable, 4) comparison, 5) variable, 6) comparison, 7) sky, and 8) check star (optional). The reason for bracketing (observing the comparison both before and after) the variable twice is accuracy — the average of two measurements will give better results than a single measurement. In fact, many people prefer to measure the variable three times, particularly if it is faint or the seeing is questionable.

Similarly, sky readings are often performed after each stellar reading. This is particularly valuable when the variable is faint or if there is any indication that the sky brightness is not constant.

The check star is usually measured only a few times each night; its purpose is to make sure that the comparison star is nonvariable. (If the difference between the comparison star and check star measurements does not stay constant over an evening, then either one of the stars must be variable or your data is flawed in some way.)

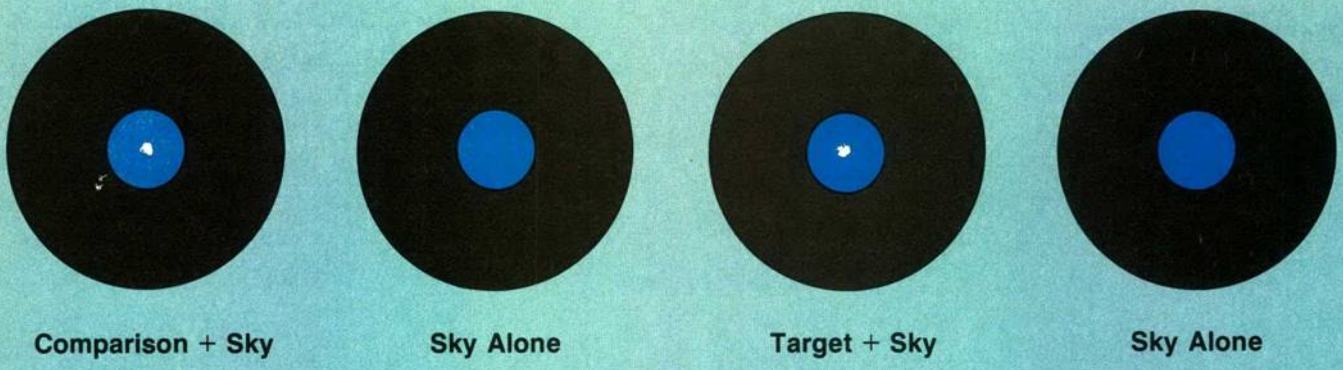
If you observe through more than one filter, the above sequence of measurements must be performed with each filter used.

A typical observing program might consist of viewing four or five long-period variable stars about once a week. Since they have long periods, these stars do not vary rapidly so once a week is adequate coverage. Observations should continue throughout a full cycle to get a complete picture of the star's variability. This kind of program is particularly well-suited for individuals living under less than ideal weather conditions who cannot count on clear weather.

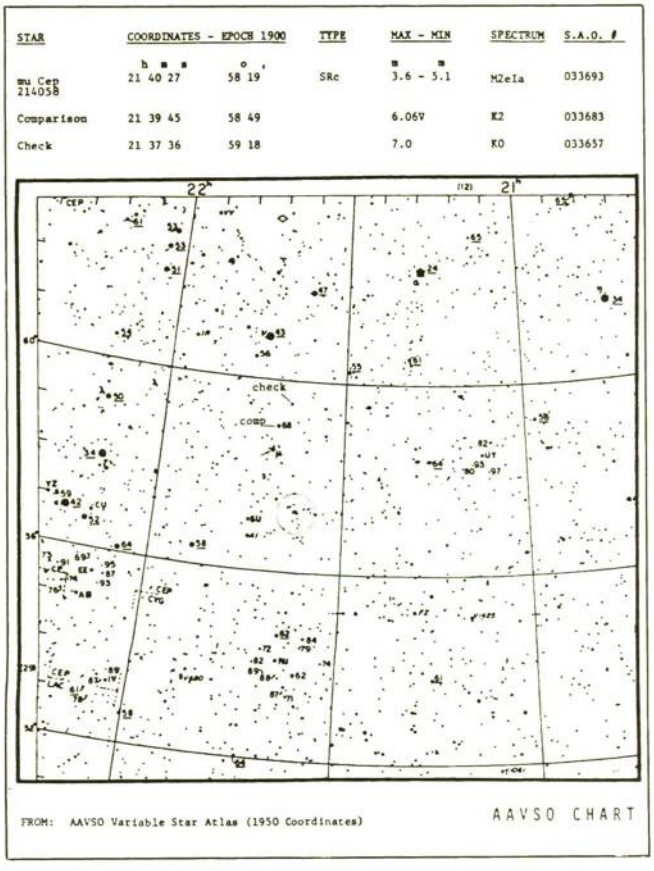
Producing Scientific Data

As you take each measurement, the results are displayed on a digital readout, strip chart recorder, or sent directly to a computer. If you are working with the AAVSO, they will supply you with observing logs to record your raw observations. The layout of this form is

Making the Observations



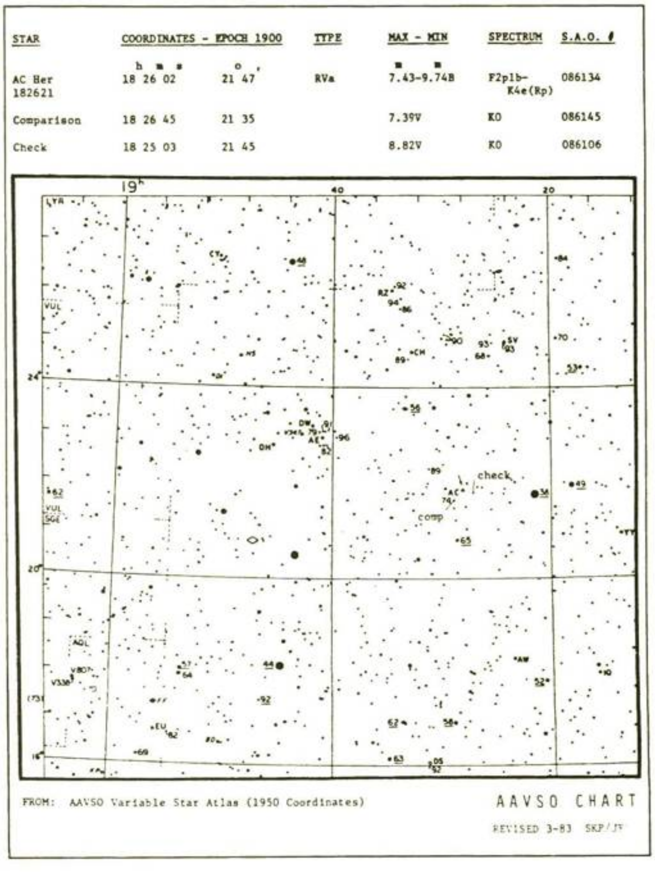
The steps necessary in making photometric observations are shown here, though the exact sequence may vary. The basic goal is to observe your program object and a comparison star while frequently measuring the sky background. First take a reading of the comparison star. Unfortunately, there will always be some sky background contributing to the total light. To subtract this effect, offset your telescope slightly and take a reading of the sky alone. Then repeat this process with the target The number of times you measure the target, the comparison star, and the sky background will depend on observing conditions and the accuracy desired.



STAR	COORDINATES - EPOCH 1900		TYPE	MAX - MIN	SPECTRUM	S.A.O. #
	h m s	° ′		m m		
mu Cep 214058	21 40 27	58 19	SRc	3.6 - 5.1	M2eIa	033693
Comparison	21 39 45	58 49		6.06V	K2	033683
Check	21 37 36	59 18		7.0	K0	033657

FROM: AAVSO Variable Star Atlas (1950 Coordinates)

AAVSO CHART



STAR	COORDINATES - EPOCH 1900		TYPE	MAX - MIN	SPECTRUM	S.A.O. #
	h m s	° ′		m m		
AC Her 182621	18 26 02	21 47	RVa	7.43-9.74B	F2pIb- K4e(Rp)	086134
Comparison	18 26 45	21 35		7.39V	K0	086145
Check	18 25 03	21 45		8.82V	K0	086106

FROM: AAVSO Variable Star Atlas (1950 Coordinates)

AAVSO CHART

REVISED 3-83 SKP/JV

An AAVSO finder chart for the semiregular variable Mu Cephei (left). Although its long-term variations have been observed visually for decades, there may be some small-amplitude periodic variations amenable to photoelectric measurements. AC Herculis is an RV Tauri-type variable star in need of good photoelectric coverage (right). Finder charts courtesy of Janet Mattei.

What Do They Mean?

OBSERVING LOG

Time	Comparison	Sky	Variable	Sky
1:15	1647	68	3045	72
1:19	1630	59	3030	65
1:23	1634	64	3039	68
1:27	1642	67	3044	73
1:31	1632	62	3037	67
Average of the above readings:				
1:23	1637	64	3039	69

Plotting a light curve from your differential photometry data is fairly easy to do and can give you a sense of what your observations show. Let's say you are observing a long-period variable star once each week from a reasonably light-polluted sky. Because of the less than ideal observing conditions, you'll want to measure the sky background after each variable reading and each comparison reading. Your observing log may look something like the one shown above.

Once you have averaged the values together, you are ready to determine the brightness of the variable and comparison star. This is done by subtracting the sky reading from the star readings, resulting in an average comparison star reading of 1573 and variable star reading of 2970.

The final step is to calculate the differential magnitude on a calculator using the formula: Diff. Mag. = 2.5 log (Comp/Var). In this case, the differential magnitude works out to −0.69 meaning that the variable is .69 magnitudes brighter than the comparison star.

You can now plot your result on a light curve, with the horizontal coordinate being the day of observation and the vertical coordinate being the differential magnitude (or apparent magnitude if you add the differential magnitude to the magnitude of the comparison star). One point would be added to the light curve each week as you continue monitoring the light variations.

The procedure for analyzing your data remains the same regardless of the type of object you observe. The only major difference is that you will need to observe more frequently than once a week if you work with shorter period variable stars or with asteroids.

straightforward: it asks for information about you, the time of each observation, the filters used, and your photometer readings. A copy of your report can then be sent to the AAVSO where it will be checked by the chairman of their photoelectric photometry committee. If there are any problems, the chairman will get in touch with you and help with any questions you may have.

Once any problems are solved and you have established a good reputation, the reports will be entered into the AAVSO computer for analysis. Here they are combined with the results from other observers working on the same variable. This processed information remains archived until a professional astronomer requests it for his or her research. This happens quite frequently, particularly for those stars that have special observing requests.

For those amateurs interested in what their observations show, it is relatively easy to plot a light curve from differential photometric data. The box above shows how this is done.

Your data can be used to determine the period of variable stars, quantify small amplitude changes in variables otherwise observed, and detect changes in the behavior of a star over time. For stars without an established light curve, your data can help to classify the variable. Finally, when used in conjunction with spectroscopic and other studies, photometric observations can zero in on the physical processes taking place within the variable star.

Asteroids

Although variable stars still get the lion's share of attention from backyard photometrists, there is now a developing interest in exploring objects from our own solar system. Asteroids are probably the most tractable such objects.

At first glance it doesn't seem possible that much can be learned from the meager light of asteroids. They appear as little more than tiny points of light in a telescope's eyepiece, even when viewed with high magnification. However, many fundamental facts about asteroids can be learned from photometric observations.

Like variable stars, their light output usually varies but for entirely different reasons. In fact, light output is a misnomer since asteroids shine only by reflected sunlight. This implies that any such variation must be caused by variations of the asteroid itself — the first clue that something of interest can be learned.

Most of the minor planets are small and not spherical. As they rotate on their axes, different parts of them point toward Earth. Since the light we receive from asteroids depends on the amount of reflecting surface they have, charting the variations gives us a measure of their shape. There are even a few asteroids (4 Vesta is the best example) that are spherical and still show brightness variations. This is due to uneven color distribution, presumably from variations in surface composition.

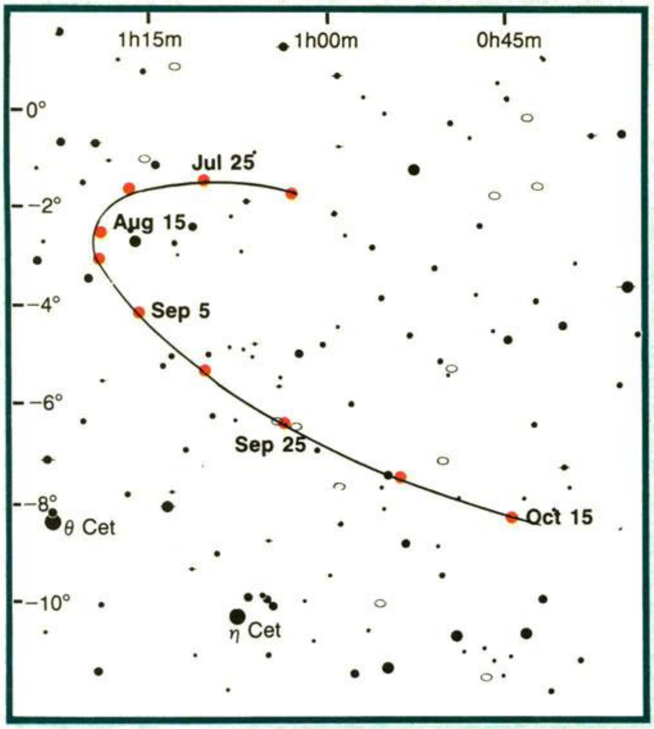
A direct inference from a light curve is the period of rotation and, if several observations exist, we can deduce the orientation of the rotation axis. In addition, photoelectric photometry can give us information on the size and albedo of asteroids.

Choosing an observing program for asteroids is not easy and may even be disappointing since only the brightest asteroids can normally be monitored with typical backyard instruments. Fortunately, professionals have concentrated on the fainter objects so there is still much work to be done with brighter asteroids. The table on page 62 lists some of the asteroids that are within easy reach of 8-inch or larger scopes.

There are also many asteroids that can be monitored at favorable opposition. Since many asteroids have markedly noncircular orbits, their distances from Earth at opposition can vary substantially. When an asteroid's perihelion occurs near its opposition date, we have a perihelic opposition (just like Mars is experiencing now) and the asteroid appears much brighter. For example, 433 Eros is quite faint at most oppositions, but approximately every 44 years it experiences a perihelic opposition. The last time that happened was in 1975, when it was bright enough to be seen easily in binoculars.

Finding Your Target

One of the most difficult parts of doing photoelectric photometry of asteroids is finding them. Being members of the solar



Making a finder chart for an asteroid requires a bit of work. Because asteroids move relative to the background stars, you must have a set of coordinates for the asteroid and plot these positions on a star chart. Shown is a finder chart for Vesta with positions marked every ten days. You can correlate it with the Star Dome map on page 52 using Eta (η) Ceti and star hop from there.

Asteroid Data Table

Asteroid	Period	Amplitude
1 Ceres	9.08	0.04
2 Pallas	7.81	0.12 - 0.15
3 Juno	7.21	0.15
4 Vesta	5.34	0.10 - 0.14
5 Astraea	16.81	0.21 - 0.27
6 Hebe	7.27	0.06 - 0.19
7 Iris	7.14	0.04 - 0.29
8 Flora	13.6	0.01 - 0.04
9 Metis	5.06	0.06 - 0.26
10 Hygiea	18.	0.09 - 0.21
11 Parthenope	10.67	0.07 - 0.12
12 Victoria	8.65	0.20 - 0.33
13 Egeria	7.05	0.12
14 Irene	9.35	0.04 - 0.10
15 Eunomia	6.08	0.42 - 0.53
16 Psyche	4.30	0.11 - 0.32
17 Thetis	12.28	0.12 - 0.36
18 Melpomene	11.57	0.15 - 0.35
19 Fortuna	7.46	0.25

This is a selected list of asteroids that reach opposition magnitudes brighter than 10.5. The period is measured in hours and the amplitude in magnitudes. For a more complete list, see the *Solar System Photometry Handbook*.

system, these objects do not stay stationary like the stars. Because of this you will need an ephemeris and star atlas to make your own finder charts, which must be accurate enough to be unambiguous. The best time to observe an asteroid is at New Moon during the few weeks on either side of opposition.

Since most asteroids have rotation periods between 4 and 12 hours, it is sometimes possible to monitor a full period in one night. Simply begin your observations about half a period before the asteroid crosses the meridian and continue to measure it for the same length of time afterward. For asteroids with periods longer than one night, observations have to be continued over a few days.

Although being able to make valuable observations over a short period of time may seem like an advantage, the difficulty in finding suitable comparison stars necessary for differential photometry is certainly a disadvantage. Because asteroids move, it is impossible to use preselected comparison stars.

The criteria for temporary comparison stars are quite stringent. The first rule for any comparison star is that it should be no more than 1° away from the target. This minimizes any difference in sky conditions between the two objects. If they were far apart you would be looking through different amounts of atmosphere; the one closer to the horizon would be relatively dimmer. Similarly, the sky background varies from one location to another for a variety of reasons.

The second rule is the most obvious but sometimes the most difficult in practice: the comparison star must not be variable. The third rule is not to choose a red comparison star for the simple reason that most red stars are variable. The fourth rule holds that the comparison and target should be similar in color. Rule five is that they should be nearly equal in magnitude.

These last two rules are actually guidelines rather than rules since it is difficult in practice to find such a star. A good finder chart and star catalogue will come in handy in your attempts to find an appropriate comparison. If all else fails, you can search the field surrounding the target until a reasonable comparison is found.

At the telescope, your observations are conducted in the same manner as for variable stars. You still take sky readings and bracket the asteroid measurements with comparison star readings. The only major difference is in timing: for an asteroid with a period measured in hours, you'll want to run through an observing cycle every ten to twenty minutes. This could cause problems when working with more than one filter, so most beginners stick with one when observing asteroids.

Sharing Your Data

After collecting your data, you can share the results with other amateurs and professionals. The organization that facilitates this exchange is the Minor Planet Section of the Association of Lunar and Planetary Observers (ALPO). They accept amateur observations, analyze the data, and comment on the reports. The organization also publishes a quarterly journal called *The Minor Planet Bulletin* that features articles written by amateurs as well as graphs, tables, charts, and asteroidal targets for photometrists in the coming three months.

Your final data can be reduced in the same manner as variable star data. The finished light curve gives you a direct measure of the asteroid's period of rotation. The amplitude of the curve (most asteroids have amplitudes of a few tenths of a magnitude) gives information on the shape of non-spherical asteroids and the degree of surface regularity for any asteroid. Used in conjunction with other observations, your data can also help determine the direction of an asteroid's rotation axis, the size of the asteroid, and its albedo.

The sky is open to everyone and there are many paths that an amateur can choose to follow. Photoelectric photometry is one of those paths. It may not be a very easy path and it is certainly not meant for everyone, but the sense of accomplishment, the feeling of contributing to the science of astronomy, and the excitement it brings is difficult to beat.

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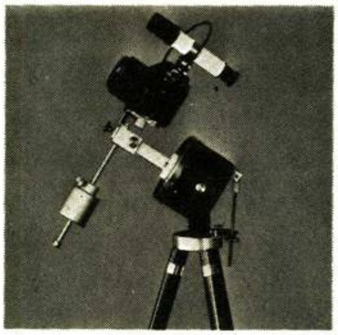

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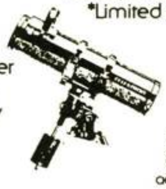

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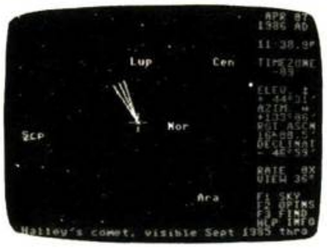

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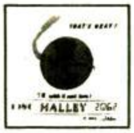

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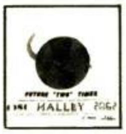

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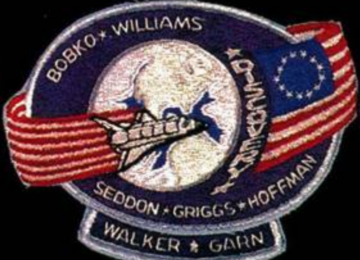
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ASTRONOMY
AstroNews

Was the Moon Formed by a Giant Collision?

The origin of the Moon has long been one of the most tantalizing questions facing astronomers. A new computer simulation supports the relatively recent idea that the Moon formed following a glancing collision between Earth and a planet-sized body early in the history of the solar system.

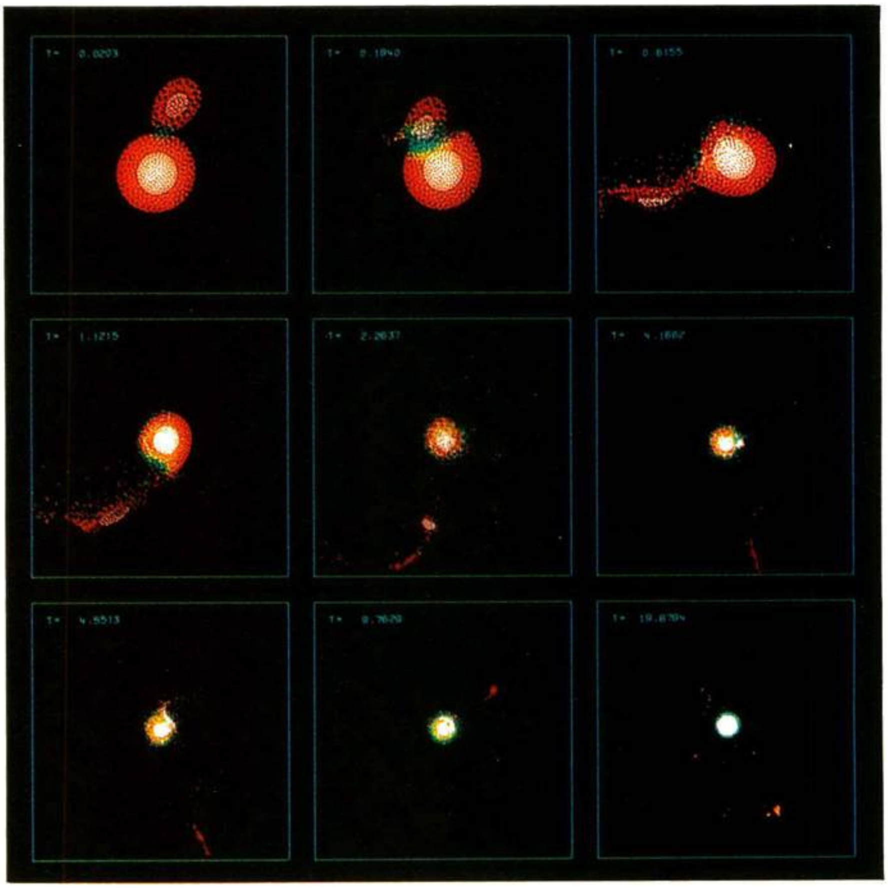
Willy Benz and Wayne Slattery of Los Alamos National Laboratory and Alastair Cameron of the Harvard-Smithsonian Center for Astrophysics reported these findings at the Lunar and Planetary Science Conference at Johnson Space Center in Houston on March 20.

The researchers initially became interested in the new theory because of deficiencies in the three most widely accepted explanations of lunar origin. The fission theory holds that Earth divided into two bodies while spinning very rapidly during its formation. It is unlikely, however, that Earth could ever have rotated fast enough to split, and even if it had, it should not be spinning so slowly today.

The capture theory proposes that the Moon formed elsewhere in the solar system and was captured following a close encounter with Earth. Although certainly possible, the probability of such a capture is remote. Also, the orbit of a captured moon most likely would not be as regular as our Moon's is.

The third theory holds that the Moon and Earth formed at the same time and from the same material. Although no one is sure which theory is correct, most astronomers have leaned toward this last explanation.

Instead of settling this dispute, the Moon rocks brought back by the Apollo missions have only added to the problem. Analysis of lunar samples indicates that only about 2 percent of the Moon's mass is located in an iron core, compared to approximately 30 percent for the Earth. In addition, elements with low melting points are less abundant on the Moon. None of the earlier theories could account for these findings.



A computer simulation of the impact between a planet-sized body and the proto-Earth shows how the Moon could have formed. The iron cores of the objects are shown in white and the granite mantles appear in red. Time is given in hours after impact at the upper left of each frame. (The Earth's decrease in size over time is due to a change in scale.)

The new theory, originated by Cameron and William Ward, proposes that a planetary body struck the Earth, causing material from the mantles of both objects to be thrown into space. Within a few hours, the material moved far enough from Earth to accrete by its own gravity and form the Moon. Because the lunar material came solely from the outer regions of both objects, it would contain very little iron from the cores. The high temperatures produced by the collision would have vaporized the more volatile elements.

Using the supercomputers at Los Alamos to perform the complex calculations, the researchers experimented with different hypothetical masses and compositions for the planetary body and the proto-Earth. They initially chose granite for the composition of both bodies, with the Earth being about nine-tenths its present mass and the planetary body one-tenth that size. In this model, the material from the impact was able to clump together from self-gravity, but it subsequently returned close to Earth and was destroyed by tidal forces.

Next the researchers increased the mass of the colliding body and added iron cores to both it and the proto-Earth. Although the impact resulted in an orbiting disk of mantle material, the disk was not massive enough to form a moon.

The most recent calculations assume the colliding body to be one-seventh as massive as the proto-Earth, a value approximately equal to the mass of Mars. Each body consists of an iron core, which makes up one-third its total mass, and is surrounded by a granite mantle. The collision occurs at a relative speed of 11 kilometers per second.

The colliding body is partially destroyed by the impact and its iron core completely separates from the mantle. Four hours after the initial collision, the core strikes the Earth again and is swallowed. Some of the mantle material thrown into space by the collision clumps together by self-gravity to produce a granite object orbiting the Earth that is almost exactly the Moon's mass.

Asteroids Named For Challenger Astronauts

As announced in the March 26, 1986 issue of the *Minor Planet Circulars*, three astronomers at Lowell Observatory in Arizona have named asteroids in honor of the seven crew members killed in the Challenger explosion last January 28. The memorial was suggested by Brian Marsden of the Central Bureau for Astronomical Telegrams in Cambridge, Massachusetts, and carried out by Edward Bowell, Brian Skiff, and Norman G. Thomas, scientists in Lowell's asteroid discovery program which is funded by NASA.

The seven asteroids were found by the Lowell astronomers on plates taken between August 1980 and March 1984 with the observatory's 13-inch astrographic telescope, the instrument used to discover Pluto in 1930. The asteroids are:

- 3350 Scobee (1980 PJ). Discovered by E. Bowell on August 8, 1980. Named in memory of Francis R. Scobee, Commander (1939-1986).
- 3351 Smith (1980 RN1). Discovered by E. Bowell on September 7, 1980. Named in memory of Michael J. Smith, pilot (1945-1986).
- 3352 McAuliffe (1981 CW). Discovered by N. Thomas on February 6, 1981. Named in memory of S. Christa C. McAuliffe, teacher-observer (1948-1986).
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E. Bowell on December 20, 1981. Named in memory of Gregory B. Jarvis, payload specialist (1944-1986).

- 3354 McNair (1984 CW). Discovered by E. Bowell on February 8, 1984. Named in memory of Ronald E. McNair, mission specialist (1950-1986).
- 3355 Onizuka (1984 CC1). Discovered by E. Bowell on February 8, 1984. Named in memory of Ellison S. Onizuka, mission specialist (1946-1986).
- 3356 Resnik (1984 EU). Discovered by E. Bowell on March 6, 1984. Named in memory of Judith A. Resnik, mission specialist (1949-1986).

All of the asteroids are main belt objects except for 3352 McAuliffe, which has a near-Earth orbit, and 3352 Jarvis, which has an unusual nearly circular orbit. The Lowell astronomers estimate that the seven asteroids range from about 1 mile (3352 McAuliffe) to 8 miles (3351 Smith) in diameter.

The Challenger astronauts are also being honored by a memorial to be built at the Kennedy Space Center in Florida by NASA using funds from a private, non-profit foundation. Contributions to the memorial fund may be sent to: Astro Memorial Foundation, P.O. Box 628003, Orlando, FL 32862.

In addition to the Challenger Seven, the memorial will honor astronauts Virgil I. "Gus" Grissom, Edward H. White II, and Roger Chaffee, who died in the Apollo 1 fire in 1967; Gemini IX astronauts Charles Bassett and Elliott See, who were killed in a T-38 jet trainer crash in 1966; Theodore Freeman, who died in a T-38 crash in 1964; Clifton Williams, who died in a T-38 crash in 1967; and Edward Givens, who died in an automobile accident in 1967.

Cepheid Variables Discovered in M-101

Two Cepheid variables have been discovered in the face-on spiral galaxy M-101 in Ursa Major. Astronomers Kem H. Cook and Marc Aaronson of the University of Arizona, and Garth Illingworth of Kitt Peak National Observatory, report in the February 15, 1986, issue of the *Astrophysical Journal* that the two Cepheids are located 9 arcminutes west and 3 arcminutes south of the galaxy's nucleus, approximately 43 arcseconds apart.

As the nearest face-on Sc-type spiral galaxy, M-101 has had a major role in astronomers' efforts to determine cosmological distances. Over the last decade, in particular, the thrust of research has been toward further calibrating the relation between the intrinsic luminosities of supergiants in M-101 and the galaxy's distance.

A stumbling block has been that the distances derived for red and blue supergiants in M-101 differ by nearly a full magnitude. (The distance of a star is derived from the difference between its apparent and absolute magnitudes, a value that, usually after correcting for absorption by interstellar dust, can be converted to a distance.) The current given distance to M-101 is 5.2 megaparsecs.

With the discovery of the Cepheids in M-101, the distance to that galaxy can now be more accurately determined from their period-luminosity relationships. (The longer the period of the Cepheid, the greater its luminosity and hence its absolute magnitude.) This, in turn, should enable astronomers to better assess the intrinsic luminosities of the supergiants. Once the luminosities of the supergiants are pinned down, these "standard candles" can be applied to even more distant galaxies.

Archiving Children's Views of Halley's Comet

Children ages ten years and younger who have seen Halley's Comet this year, and have the opportunity to see it again in 2061, can record their impressions for posterity.

The Planetary Society has established an archive for essays, pictures, and cassette recordings of children's impressions of Halley in 1986 and their views of what the comet will look like when it returns in 76 years.

"Today, people who saw Halley's Comet in 1910 are sharing their recollections," says Louis Friedman, executive director of the Planetary Society. "We should not forget to preserve the impressions of children who will experience the 1986 appearance of the comet and perhaps the 2061 appearance as well."

Roger Bonnet, director of Space Science for the European Space Agency, suggested the project to the Planetary Society after establishing a similar archive in Europe last winter. The International Halley Watch is working in cooperation with the Society on the project.

Submissions to the archive should be no more than one page for pictures and essays and one minute for taped recordings. Entries can be sent to the Planetary Society, 65 N. Catalina Ave., Pasadena, CA 91106. Children who submit material will receive a print of an image taken during the March spacecraft encounters with Halley's Comet.

White Dwarf Exhibits Strongest Magnetic Field

The strongest magnetic field yet measured in the universe has been detected around a newly discovered white dwarf star in the constellation Sextans. The star, designated PG 1031+234 (which denotes the star's right ascension and declination) is estimated to have a magnetic field 700

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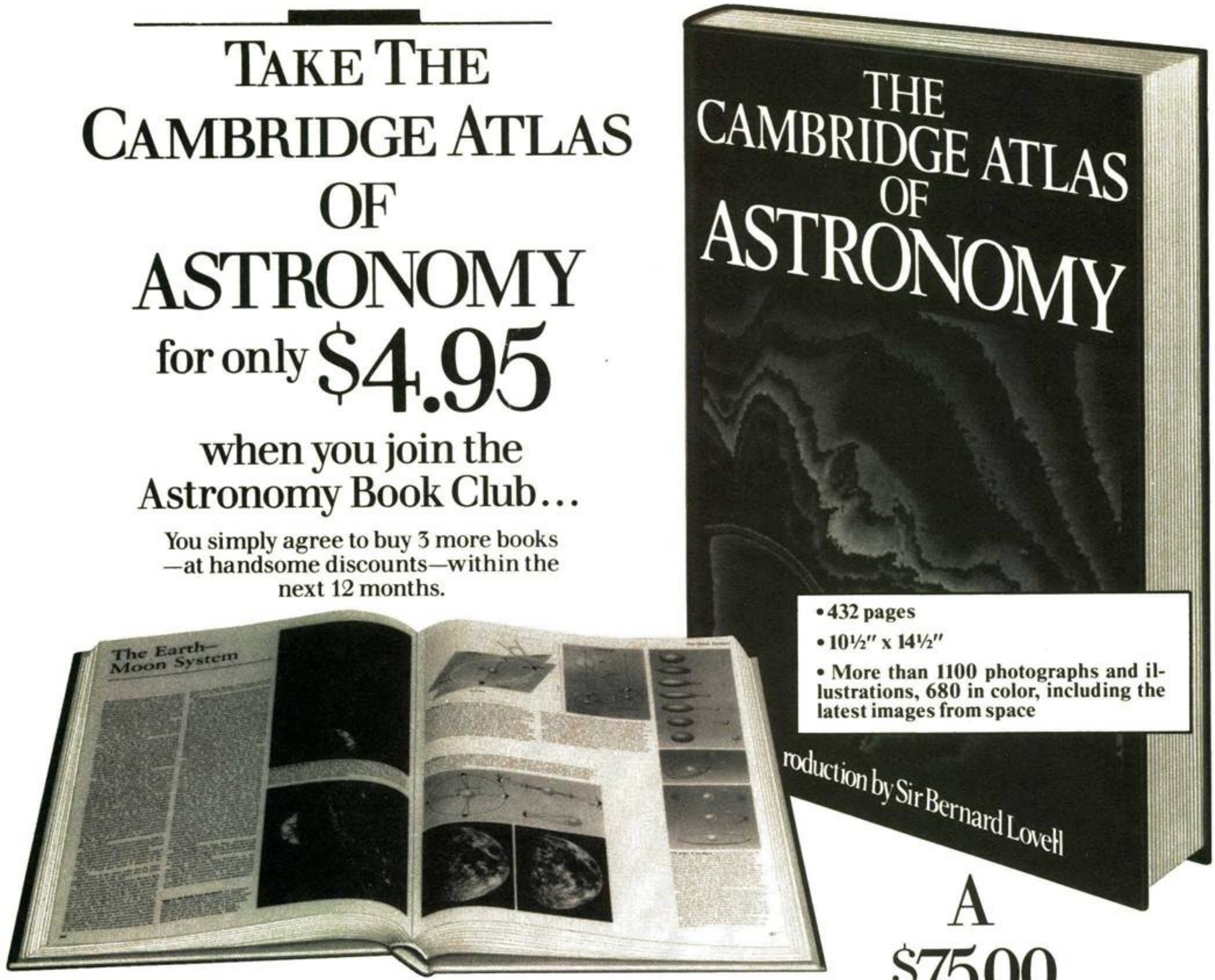
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million times stronger than Earth's. It is one of only two dozen white dwarf stars known to have exceptionally strong magnetic fields.

Astronomers Gary D. Schmidt of the University of Arizona, Steven C. West and James Liebert of Steward Observatory, Richard F. Green of Kitt Peak, and H.S. Stockman of the Space Telescope Institute discovered the white dwarf with the 5-meter telescope at Palomar Mountain Observatory and the Steward Observatory's 2.3-meter telescope on Kitt Peak. They also used spectrophotometric data taken from the International Ultraviolet Explorer Observatory satellite.

It is likely that PG 1031+234 was once a normal star and that its magnetic field was established early in its lifetime. When the spent star collapsed, the magnetic field contracted with it and, in accordance with the property of angular momentum, was amplified to the 700 million gauss level it exhibits today. In comparison, the Earth's magnetic field measures 1 gauss and that of an average sunspot equals a few thousand gauss.

Unlike most white dwarfs that rotate slowly, PG 1031+234 rotates once every three hours and twenty-four minutes, another by-product of the star's collapse. The rotation, according to Schmidt, allows astronomers to study the magnetic field from many different perspectives. Observations reveal a very complex magnetic field tilted sharply from the star's rotational axis with a strong magnetic region located near the magnetic equator.

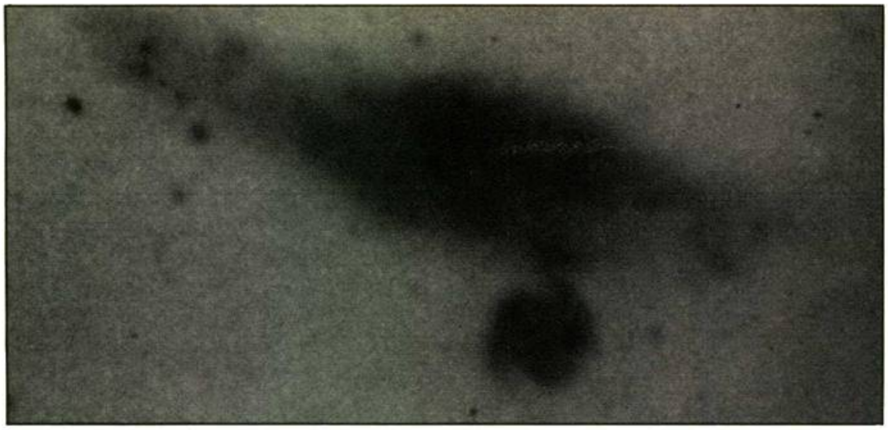
The extraordinary circumstances posed by the strong magnetic field surrounding this and other white dwarf (as well as neutron) stars will enable astronomers to study more common, weaker magnetic fields and how they affect stellar atmospheres.

The Redshift Connection

Analyses of galaxy observations have revealed evidence of gravitational interaction between the members of two pairs of galaxies, even though each member in the pair has a radically different redshift. If the existence of such a system can be confirmed, it will directly challenge the use of extragalactic redshifts as distance indicators.

Generally, the shift of lines in the spectrum of a galaxy or quasar toward longer wavelengths has been interpreted as a direct measure of an object's distance. Two or more objects grouped together and exhibiting similar redshifts are regarded as being at the same distance. Grouped systems with different redshifts have been regarded as being chance optical alignments of objects at different distances. However, recent observations of two systems, each with connecting bridges of material but exhibiting different redshifts, challenge these views.

These findings were reported in the



NGC-4151 and the smaller spiral NGC-4146 appear to be interacting even though they have radically different redshifts. Photo courtesy of the JPL Image Processing Laboratory.

October 15, 1985, issue of the *Astrophysical Journal* by J.W. Sulentic of the University of Alabama and Halton C. Arp of Mount Wilson and Las Campanas Observatories. Using a charge-coupled device with the 4-meter Mayall telescope on Kitt Peak, Sulentic and Arp recorded images of two pairs of apparently interacting galaxies: the spiral NGC-4030 and companion NGC-4011 in Virgo, and the bright Seyfert galaxy NGC-4151 and its companion NGC-4146 in Canes Venatici. In both cases, a bridge of gas can be seen extending from the larger of the two galaxies to their smaller companions. The direction of the gas was determined by spectroscopically tracing the areas of the strongest emission, Hα, from the center of the larger galaxy directly into the smaller companion.

The connections are made more intriguing by the fact that in both cases, the smaller members exhibit significantly higher redshift values than their larger partners. According to Sulentic and Arp, the unique distribution of excited gas from the lesser to the higher red-shifted objects indicates that both pairs of galaxies are interacting.

These galaxies represent the first discordant redshift systems for which spectroscopic peculiarities have been found.

Streaming Galaxies Challenge Uniform Expansion Theories

A group of American and British astronomers reports that galaxies in a volume of the universe measuring roughly 350 million light-years in diameter are moving through space apparently independent of the motion attributed to the expansion of the universe. The seven-member team made their presentation in Hawaii last January at the NATO Workshop on the Extragalactic Distance Scale and Deviations from Hubble Expansion.

Astronomers learned early in this century that all galaxies are rushing away from each other at a rate determined by the Big Bang. In addition to this orderly expansion motion, galaxies also exhibit random or "peculiar" motions, usually attributable to the gravitational influences of nearby large concentrations of mass, such as a galaxy cluster.

The velocity of our galaxy's peculiar motion has been determined to be 600 kilometers per second because the temperature of the surrounding microwave background radiation is slightly hotter (or blue-shifted) in the direction of movement. This rather high velocity was thought to be caused by the gravitational pull of both the Virgo and Hydra-Centaurus superclusters.

However, using improved distance indicators based on the orbital speeds of stars within each galaxy and the brightness of each galaxy, the team of astronomers has shown that rather than being the source of gravitational pull, the two superclusters are moving in the same direction as the Milky Way at about 700 kilometers per second. Moreover, the distance between the Local Group and the Hydra-Centaurus supercluster is increasing faster than the orderly expansion rate of the universe.

The team also found that elliptical galaxies in the opposite direction of the Hydra-Centaurus group also have the same peculiar motion. The apparent direction of motion for all these galaxies is toward the Southern Cross.

One possible explanation for this motion is the existence of an immense and very distant mass concentration (greater than the mass of the Hydra-Centaurus supercluster) that is pulling the entire local region of the universe toward it. This immense mass is yet to be discovered.

Another interpretation is that the motion is a remnant of explosions of massive primordial stars in the early universe (AstroNews, May 1986). Such explosions, it has been suggested, could also explain the bubble-like structures observed in the distribution of galaxies reported by Smithsonian astronomers earlier this year.

Whichever theory is accepted, the results of these observations suggest that the universe is not expanding in the orderly manner previously believed.

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Yellowstone's Night Skies (4-day course), Yellowstone National Park, Wyoming. Contact: Gene Ball, Yellowstone Institute, P.O. Box 117, Yellowstone National Park, WY 82190. Phone (307) 344-7381 ext. 2384.

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3rd Annual Mount Kobau Star Party (superb observing, telescope-making and astrophotography contests, speakers), Okanagan Valley, British Columbia. Contact: Peter Kuzel, 4100 25th Ave., Vernon, B.C., Canada V1T 1P4. Phone (604) 545-1226.

August 2
Stellafane, Springfield, Vermont. Contact: Dennis di Cicco, 60 Victoria Rd., Sudbury, MA 01776.

August 5-10
ASTRO CON 86 (national convention of the Astronomical League), Baltimore, Maryland. Contact: ASTRO CON 86, 642 Kingston Rd., Baltimore, MD 21220.

August 8-10
STARFEST '86 (fifth annual observing convention of the North York Astronomical Association), River Place Campground, Mount Forest, Ontario, Canada. Contact: Andreas Gada, 145 St. George St., Apt. 701, Toronto, Ontario, Canada M5R 2M1.

August 10-12
Star Trails West (2-day class), Yellowstone National Park, Wyoming. Contact: Gene Ball, Yellowstone Institute, P.O. Box 117, Yellowstone National park, WY 82190. Phone (307) 344-7381 ext. 2384.

September 5-7
ASTROFEST (sponsored by the Chicago Astronomical Society), Camp Shaw-Waw-Nas-See Campsite, Illinois. Contact: Astrofest, P.O. Box 596-A, Tinley Park, IL 60477. Phone James Hansley, Chairman, (312) 764-5131.

October 2-5
Okie-Tex Star Party (sponsored by the Oklahoma City Astronomy Club), Lake Murray, Oklahoma. Contact: Joe Pearson, 700 Teal Place, Edmond, OK 73034.

October 10-12
Pacific Planetarium Association Fall Meeting, Salem, Oregon. Contact: Tom McDonough, Chemeketa Community College, 4000 Lancaster Dr. NE, P.O. Box 14007, Salem OR 97309. Phone (503) 399-5161.

January 4-8, 1987
169th Meeting of the American Astronomical Society (professional meeting sponsored by Mount Wilson Observatory and Caltech), Pasadena, California. Contact: AAS, 1816 Jefferson Pl. NW, Washington, DC 20036.

March 26-29
National Science Teachers Association National Convention, Washington, DC. Contact: Matthew R. Murphy, Conventions, NSTA, 1742 Connecticut Ave. NW, Washington, DC 20009. Phone (202) 328-5800.

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Astrophotography with Tech Pan 2415 Film

by
Mace Hooley

It used to be that amateur astrophotographers wanting observatory-quality black-and-white images had to settle for observatory-made photographs. Capturing the faint, intricate details of deep-sky objects on black-and-white film was possible only with the fast but very contrasty and grainy spectrographic emulsions in the 103a series, specifically 103a-O, 103a-E, and 103a-F.

These films are still manufactured by Kodak for scientific research, but they are expensive, hard to find in less than 150-foot lengths, and somewhat difficult to process. Moreover, the films are sensitive to different areas of the spectrum, which limits the choice of subjects that can be photographed with a particular film. 103a-O is blue sensitive, which is suitable for galaxies and reflection nebulae; 103a-E has fairly uniform sensitivity but peaks at the red end of the spectrum, so it is best suited for emission nebulae. Although 103a-F is more like regular panchromatic film, it still has the grain problem. And so we're back to square one.

Advantages of Tech Pan 2415

Fortunately, Kodak's Technical Pan 2415 has stepped in to meet the demand for a general-purpose, very fine-grained film. Though it's not perfect in all respects, it comes very close. This film's assets are its high contrast, microscopic grain, and high speed (when properly hypersensitized). Its high contrast renders elusive detail with adequate separation from the sky background, making photographing faint galaxies and nebulosity an easier task. The emulsion's very high resolution (depending on the developing solution used) can capture the finest detail in many astronomical objects.

Tech Pan is a rather "slow" film with a rated speed of ASA 125 under ordinary daylight conditions. This is one-tenth the speed of the fastest Kodak and Fuji color emulsions.

For astrophotography, Tech Pan is most effective after it has been gas hypersensitized. This procedure removes water vapor and oxygen from the film and replaces them with a mixture of nitrogen and hydrogen, which greatly reduces reciprocity failure (the film's decreasing sensitivity to light over time). Hypering also enables the film to perform at a faster speed during long exposures.

Ordinary low-contrast terrestrial films have the disadvantage of losing even more contrast when they are hypered. Fortunately, hypering does not harm 2415's contrast greatly, even if it goes unrefrigerated for a few days. Hypering effectively increases its speed by eight to twenty times its unhypered counterpart.

If you have access to a hypering kit, soak 2415 in forming gas (92 percent nitrogen, 8 percent hydrogen), for at least three days at 30°C, or as long as it takes to slightly fog the unexposed areas of the film. Higher temperatures around 48°C can be used if the soaking time is reduced to about two and a half days. If you do not have a hypering kit, hypered 2415 film can be obtained from Lumicon, Inc., in Livermore, California, and The Astrograph in Arlington, Virginia.

The biggest advantage of 2415, however, is its microscopically fine grain. A small, faint object on film can be enlarged tremendously — as much as forty times — provided the telescope/photographer can put that much detail on the film. Negatives enlarged only slightly appear truly grainless and exhibit remarkable depth and richness.

Exposing and Processing

Because of its high speed and the fact that its greatest spectral sensitivity is well away from the natural ionized oxygen band and the green mercury-vapor airglow, 2415 allows you to photograph faint stars and nebulosity through moderately light-polluted skies. For added contrast and airglow suppression, a red filter (such as the Wratten 25A or the darker red Wratten 29) may be attached to the camera lens or eyepiece.

Given a dark sky, exposures can be rather long. For example, at f/1.5, 10 minutes is the most you can expose for; at f/2.8, the exposure can be as long as 30 minutes; and at f/4, 60 minutes will be the maximum before the film becomes severely fogged. For a typical exposure, try 30 minutes with f/4 to f/6 systems. You'll probably be amazed at the results. If you use a red filter, double these times — and remember to refocus after attaching the filter!

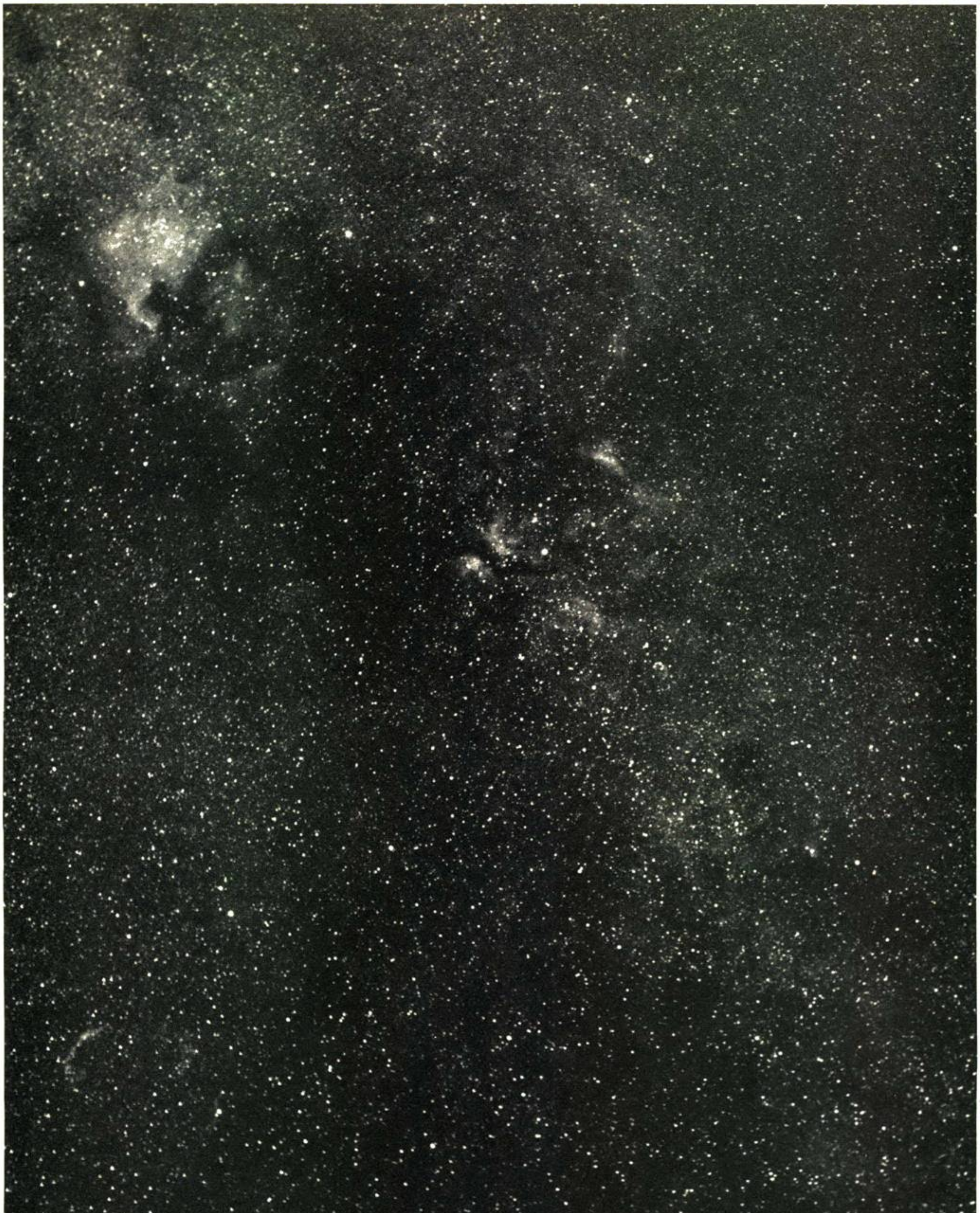
For those without a darkroom, processing Tech Pan is quite easy: 4 minutes at 68°F in D-19, a 30-second stop bath, and a 2-minute fix are all that's required. The negatives can be mounted in regular 2x2 slide mounts and copied back onto unhypered Tech Pan in a slide copier to produce stunning, high-contrast black-and-white slides.

When you want prints, any lab can treat a black-and-white positive slide as a color transparency and print it onto color reversal paper, yielding a monochrome positive image. If you have an enlarger handy, the original Tech Pan negatives will print nicely onto grade 3 or 4 paper. You can use a grain focuser under the enlarger if you like, but don't be surprised if no grain is visible.

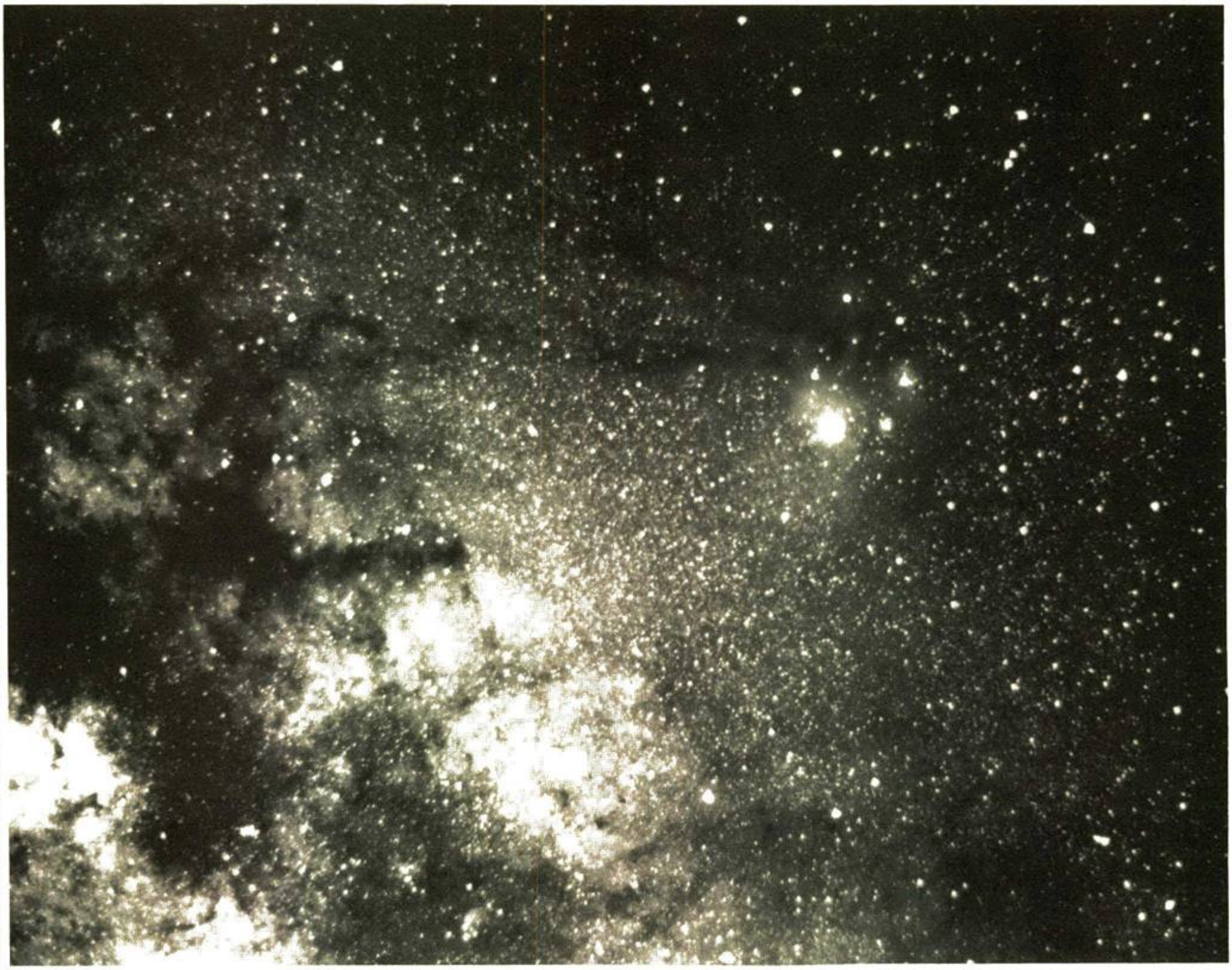
What about contrast enhancement? Perhaps you've seen ultra-high-contrast photos of familiar objects with wreaths of nebulosity that neither you nor the photographer knew were there. By copying the negative onto ordinary film you will increase the contrast, thus bringing out fainter details in the image. Contrast enhancements are easy to do. Simply make a positive of your original negative, recopy your positive in a slide copier with non-hypered 2415, then make another 2415 positive from that negative. The contrast gain is astounding. I find that the second negative usually shows much more information.

Using Tech Pan Effectively

Being such a versatile film, Tech Pan 2415 excels at nearly every type of astrophotography.

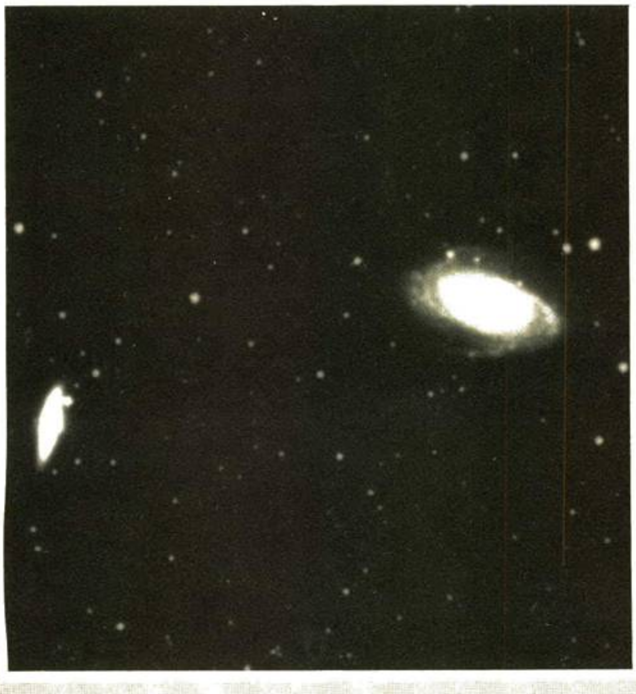


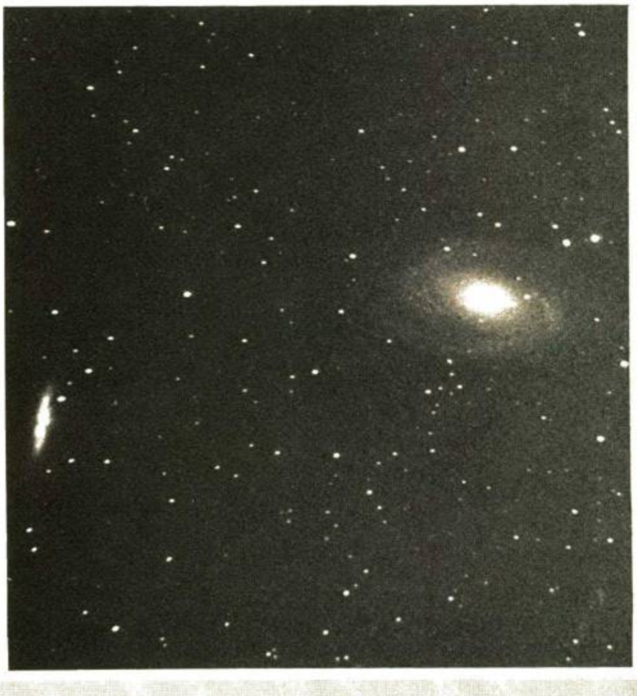
The Cygnus area of the Milky Way is an easy target with a wide-field lens and Tech Pan 2415. Note the North America Nebula in the upper left of this photo and part of the Veil Nebula in the lower left. Tom Eby took this 25-minute exposure using a 50mm f/2 lens.

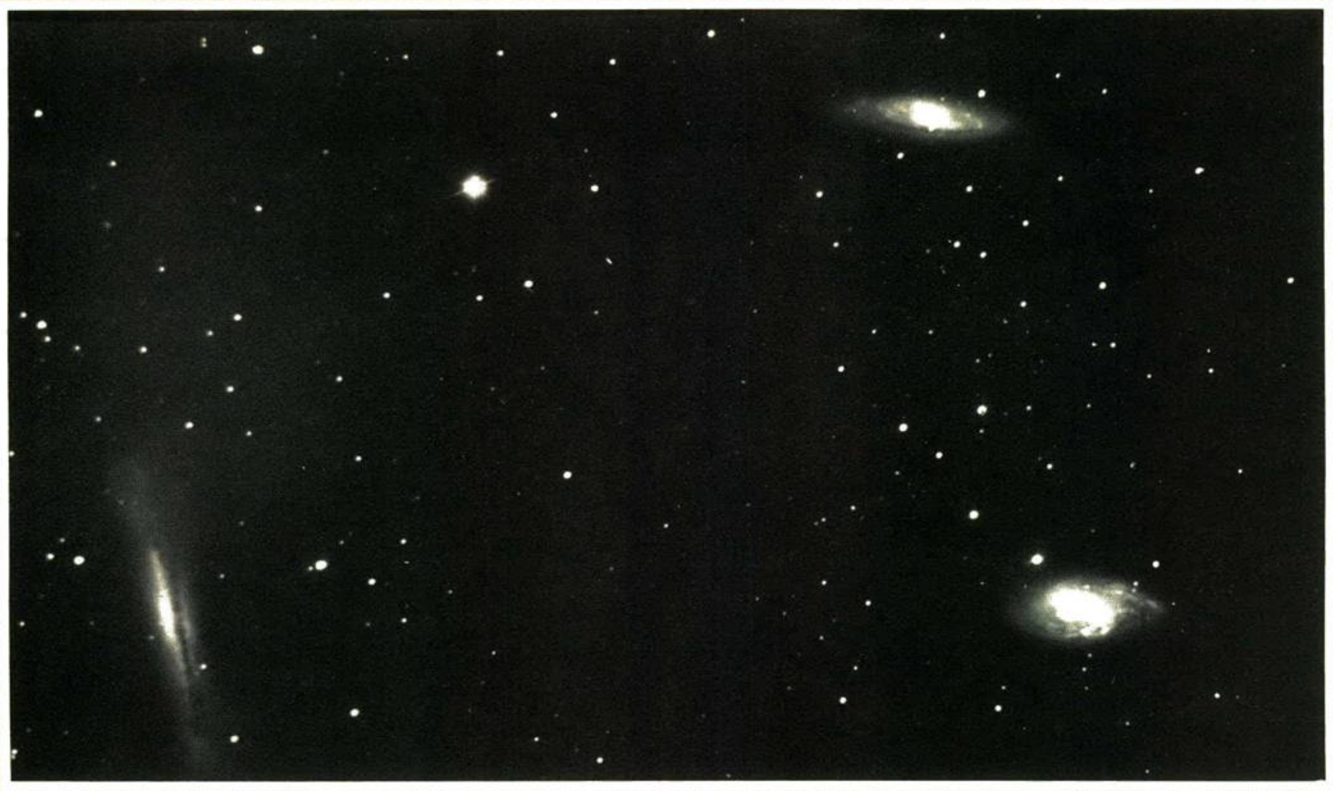


Above: The Rho Ophiuchi dust complex is revealed in this 30-minute exposure photographed at f/2.0 with a 50mm lens through a red Wratten 24A filter. Photo by Mace Hooley.

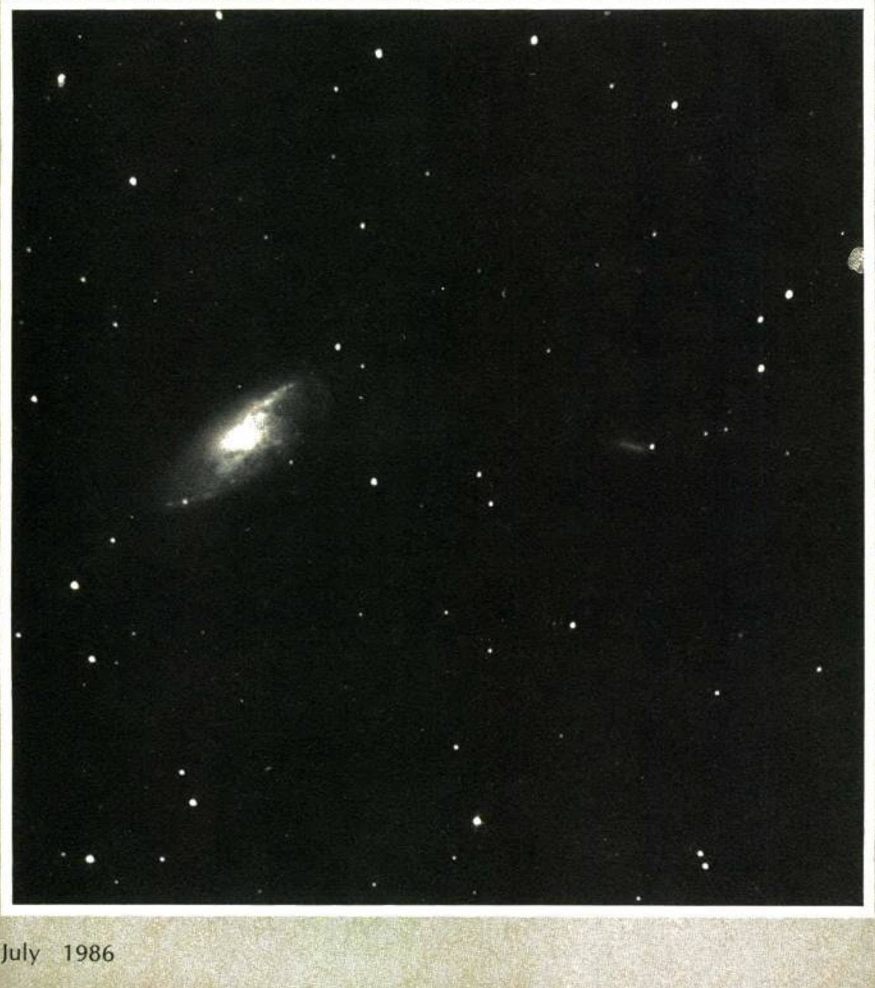
Below: Two photos of M-81 and M-82: the one at left was made using 103a-E film; at right is an exposure made with 2415 film. Notice the differences in grain and contrast. Left photo by Dale Lightfoot; right photo by Mace Hooley.







Above: M-65, M-66, and NGC-3628 photographed using an 8-inch Schmidt camera and a 10-minute exposure.
Below: The tightly wound arms of M-106 are visible in this 45-minute exposure, which was made through a 17-inch f/4.5 reflector. Spindly NGC-4217 is visible to the right of M-106. Photos by Mace Hooley.



Piggyback-mounted cameras, with their wide-angle views, work best for photographing extended fields of bright and dark interstellar nebulae and large galaxies. The Milky Way is an excellent target, as is the Antares/Rho Ophiuchi dust complex. The famous but elusive Barnard's Loop in Orion is also well within reach of 2415 film (in fact, finding a dark sky may be more challenging). At f/2 using a red filter, a 30-minute exposure should produce fine results; without a filter, expose for 10 minutes.

Tech Pan works very well with short focal-length telephoto lenses and Schmidt cameras. With an 8-inch Schmidt camera that resolves 1400 lines/mm, the 400 lines/mm capability of 2415 makes it the film of choice. Fuji 100 film, for example, will resolve about 150 lines/mm and 3M 1000 will resolve about 80 lines/mm.

With longer focal-length astrocameras and excellent seeing, Tech Pan is capable of one-arcsecond resolution, so focus and guide carefully. At f/4, an excellent exosure would be about 60 minutes, but objects like the Lagoon, Omega, and Eagle Nebulae will record well in exposures of 20 minutes or so.

The film is here, the optics are readily available, and many manufacturers are producing mounts capable of the precision tracking needed for making long exposures. With black-and-white photography on such a high plateau, anything is possible, especially with a keen astrophotographer at the controls.

Mace Hooley is an astrophotographer living in Phoenix. His last article, ''Fundamentals of Astrophotography'' appeared in the May 1986 issue.

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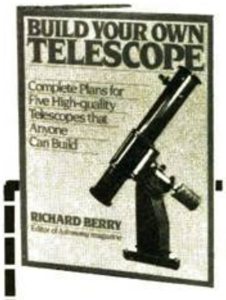
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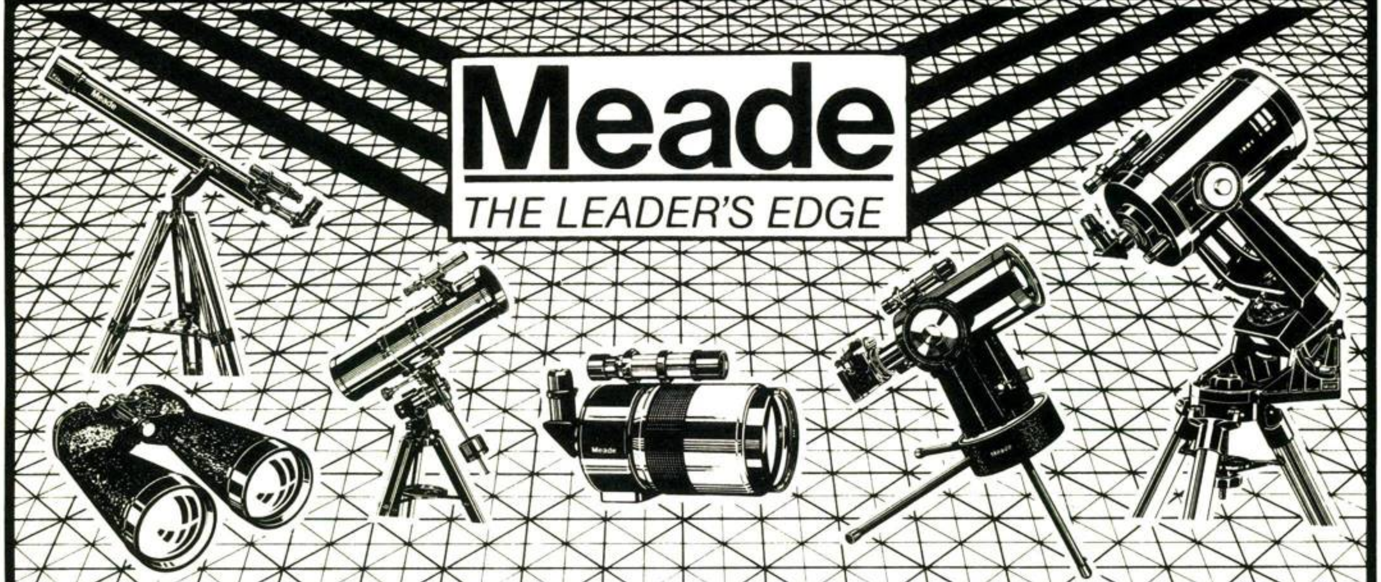

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Space Science After

by Donald F. Robertson

When the the Space Shuttle Challenger exploded seventy-two seconds after lift-off, our thoughts went to the seven astronauts who lost their lives and our hearts went to their families. But now, five months after the explosion, it is clear that much more than lives, and a yet-to-be-determined number of billions of dollars worth of equipment, were lost in that horrifyingly beautiful cloud of superheated steam.

This was to be the year in which the United States began its first major scientific assault on the solar system in nearly a decade. Launches of the Galileo Jupiter Orbiter/Probe and, with the Europeans, the Ulysses Solar Polar mission were slated for May of this year. The Hubble Space Telescope (HST) was also to have been launched later this year and was expected to open more of the universe to human inquiry than any previous telescope (see "1986: A Busy Year for the Shuttle," March 1986).

With the Shuttle fleet now grounded, there is no way to launch heavy payloads (or even many light ones), and no way at all to get humans into space. What will happen to space science in the meantime? As Samuel W. Keller, NASA's deputy associate administrator for Space Science and Applications, told ASTRONOMY in regard to the Space Telescope, "The simplistic answer is it's going to be delayed."

In retrospect, it seems clearly obvious why the disasterous loss of the Challenger will delay space exploration. Over the past few years, space science experiments have become more ambitious and have been designed to answer more fundamental questions. The instruments required for these experiments are bigger and more complex. They have increasingly needed larger vehicles and invariably a "man-in-the-loop" arrangement (humans interworking with machines) to launch, deploy, and control them. The Space Shuttle — promoted as a space-going truck — was designed to meet these demands in a single vehicle. Alternative means of getting into space, such as expendable rocket boosters, were considered not in step with NASA's reusable-rockets strategy. This approach, claim many space scientists, was NASA's biggest mistake.

The Congressional Solution

The ultimate decisions on what happens to space science after Challenger will be made by Congress, mostly during the current debate over NASA's 1987 budget. The information Congress needs to make these decisions has been compiled by the Congressional Budget Office (CBO) in a report completed last February. The report, titled *The Budget Effects of the Challenger Accident*, paints a very grim picture.

The CBO report makes the assumption that priority for payload space will not be greatly affected by the Challenger explosion and will remain what it has been: "national security (i.e. 'military') projects, payloads that must be launched within a specific time period, payloads from paying foreign and commercial customers, and NASA space science projects that do not require a specific launch time." The report compares this priority list with NASA's new launch plan, revised after the Challenger accident, which assumes a possible total of twenty flights through 1988. Adding in the military payloads planned before the accident, the report then concludes that of those twenty flights, fifteen will be military missions. That leaves only two missions for foreign and commercial customers, two for planetary exploration (presumably Galileo and Ulysses), and one for "other NASA." "Other NASA" would probably be either a Spacelab flight or the Hubble Space Telescope, each of which requires a Shuttle flight all to itself. And somewhere in this schedule NASA will have to fit at least one test flight with only two astronauts and no significant payload.

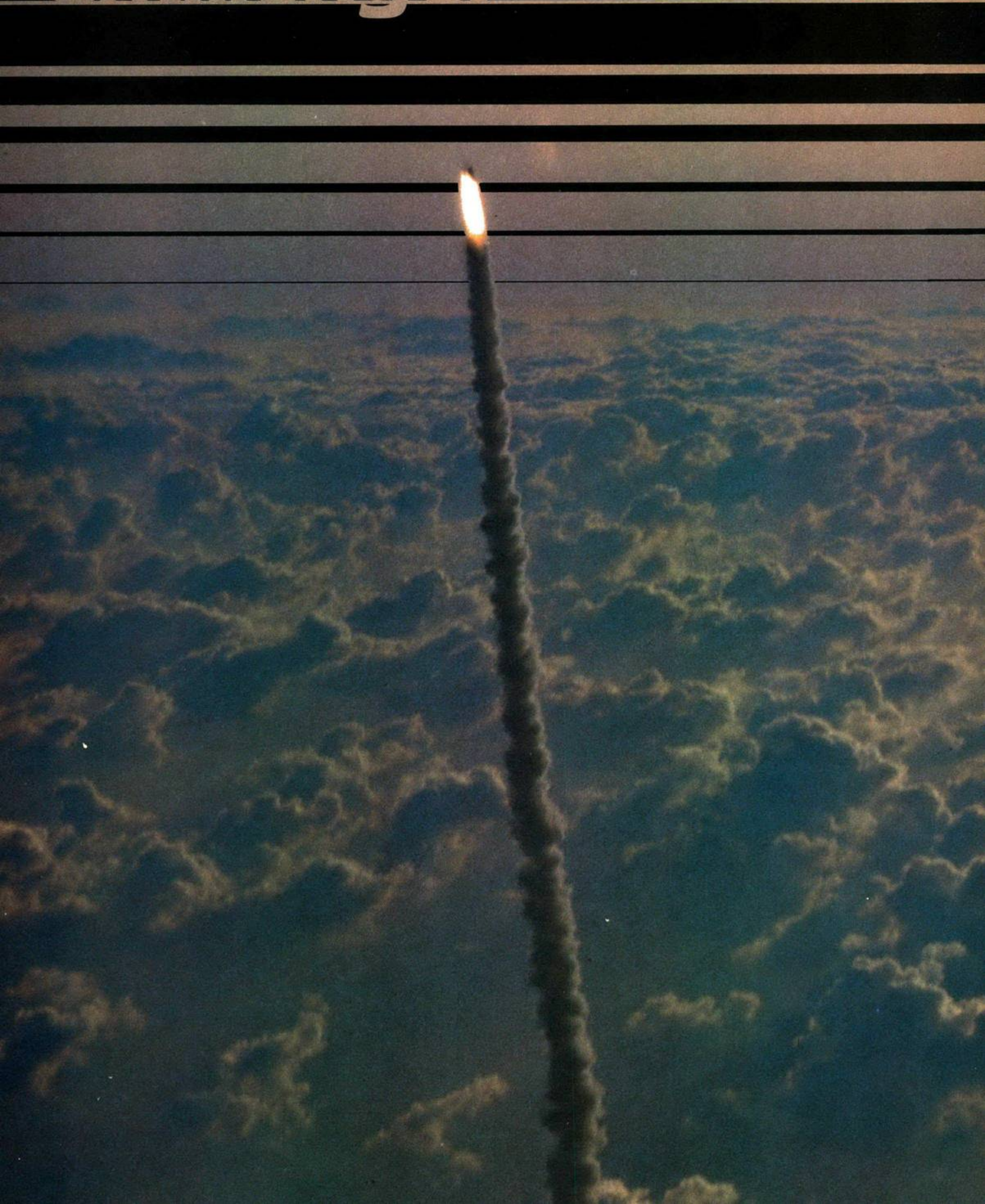
Keller said the HST is NASA's single highest scientific priority and would thus get an early launch, perhaps in 1987 or 1988, depending on whether one of the scheduled military or commercial payloads can be bumped. However, he also said the HST requires two Tracking and Data Relay Satellites (TDRS) in orbit to relay the vast quantities of information the telescope will obtain to the Space Telescope Science Institute back on the ground. Unfortunately, part of the payload that exploded along with Challenger included the second TDRS, so another will have to be launched before the HST.

All this implies that there will probably be few if any Spacelab flights for the remainder of the decade. This would be more than unfortunate since Spacelab represents Shuttle science at its best: numerous small experiments under the direct control of experimenters. There is no possibility of doing this sort of science on expendable boosters.

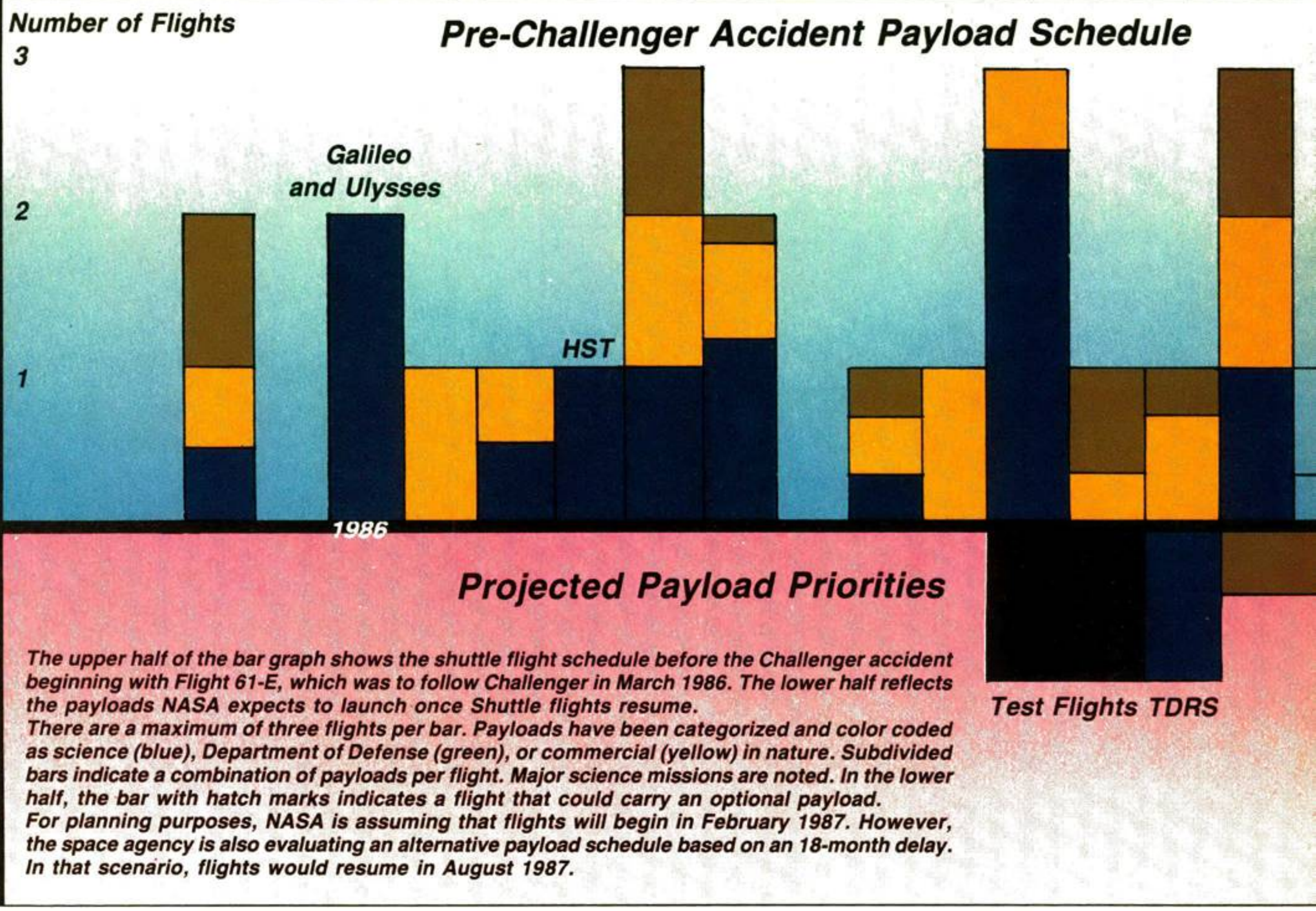
The CBO report also suggests that one way to help pay for analyzing the Challenger accident, replacing the orbiter (if that is decided), and redesigning its propulsion system would be to "reduce NASA spending over the next two to three years . . . [in] the research and development function, since the loss of Shuttle capacity will lead to a dramatic reduction in Shuttle flights available to launch R&D payloads" even beyond the start of flight operations. "Stacked-up national security payloads from 1986 and 1987, and advanced [military] requirements for 1988 leave little, if any, room on the manifest before 1989 for discretionary space science or new paying commercial and foreign payloads." In other words, there is little point in paying for science missions that cannot be launched.

Funds diverted from the Space Station to offset Shuttle repairs will probably have little impact on Space Station progress since delays in the Shuttle program will inevitably hold up space testing of Station technologies. But unless a new orbiter is built, Space Station launch requirements could tie up much of the fleet in the 1990s. Delivery of the Station to orbit is expected to require seven to twelve flights over a twelve- to eighteen-month period. Assembly will occupy a yet undetermined number of additional months and may require eight to nine flights per year. Thus, just when military requirements may be sufficiently caught up to free

Challenger



How the Payloads Stack Up



The upper half of the bar graph shows the shuttle flight schedule before the Challenger accident beginning with Flight 61-E, which was to follow Challenger in March 1986. The lower half reflects the payloads NASA expects to launch once Shuttle flights resume.
There are a maximum of three flights per bar. Payloads have been categorized and color coded as science (blue), Department of Defense (green), or commercial (yellow) in nature. Subdivided bars indicate a combination of payloads per flight. Major science missions are noted. In the lower half, the bar with hatch marks indicates a flight that could carry an optional payload.
For planning purposes, NASA is assuming that flights will begin in February 1987. However, the space agency is also evaluating an alternative payload schedule based on an 18-month delay. In that scenario, flights would resume in August 1987.

orbiter stowage for space science, Space Station requirements could tie it up again. (Europe is considering redesigning their part of the Space Station to accommodate launch on their Ariane 5 launch vehicle to relieve some of this pressure — and to avoid complete dependence upon the Space Shuttle.)

Critical Launch Deadlines and Dangers

Ulysses and Galileo are in far more trouble than either the HST or Space Station. Willis Meeks, Ulysses' project manager at NASA's Jet Propulsion Laboratory, said the spacecraft will be stored at Cape Kennedy and its radioisotope thermoelectric generator (RTG) nuclear power sources will be taken to a Department of Defense facility in Ohio. The next opportunity to send Ulysses toward Jupiter — where that planet is to gravitationally sling it over the Sun's poles — is June 1987. Launch preparations would begin at the Cape in February 1987, and spacecraft preparation would pick up again on March 1, 1987.

If Ulysses were launched during that time, solar science would not be "affected enough to mention," says Meeks, and the ability of the Shuttle and its Centaur high-energy upper stage to get the spacecraft to Jupiter "still looks good." Although Challenger was one of only two Shuttles able to carry the Centaur and its payload to Earth orbit — where the Centaur would boost the spacecraft to Jupiter — NASA associate administrator William Graham has approved modifying Discovery for this purpose while the fleet is down. A one-year launch postponement would simply delay the official end of Ulysses' mission from 1991 to 1992. The spacecraft would still fly over the Sun's south pole and, if the RTG and other equipment last long enough, also the north.

There are a number of problems with this launch scenario, however. First and foremost is the Shuttle itself. Keller believes June 1987 is uncomfortably close to the earliest possible date the Shuttle could be flying again. He thinks it unlikely that NASA will be able to fly two Shuttles within a single short Jupiter launch window so soon after the re-start of launch operations. That means either Galileo or Ulysses will have to wait yet another thirteen months until the *next* Jupiter launch window.

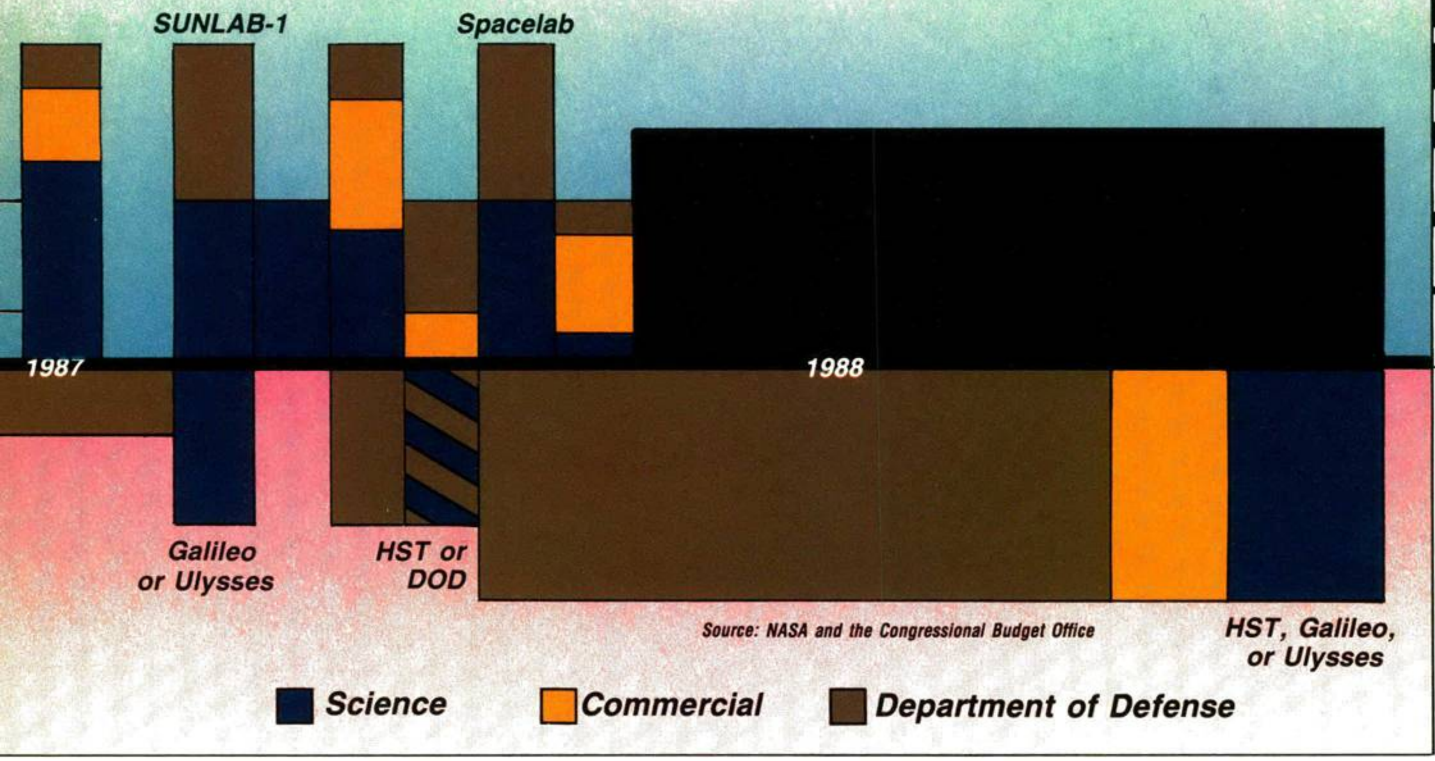
Meeks said a 1988 Ulysses launch was viable from a scientific point of view, but with that long a delay "mechanical things on the spacecraft may begin degrading" before the end of the spacecraft's mission. RTG power production, supplied by the radioactive decay of plutonium, also runs down with time and cannot be recharged like a battery. Given a two-year delay, it may become difficult or impossible to run all of Ulysses' experiments toward the end of the mission. Replacement of any of this equipment could get very expensive.

Another problem is the potential hazard posed by the Centaur upper stage. NASA management, now much more conscious of Shuttle safety, has second thoughts about flying a stage filled with liquid oxygen and liquid hydrogen (one of the most explosive chemical combinations known and, in fact, what caused the Challenger fireball) in the Shuttle's payload bay. Reports in the aerospace trade press suggest NASA may cancel the Centaur program, which would leave both Ulysses and Galileo high and dry with no way to get beyond low Earth orbit.

As if that were not enough, an old worry has resurfaced after the Challenger explosion: What would happen to the RTG nuclear power sources if the Shuttle exploded on the launch pad? Nuclear power is essential for exploration beyond Mars' orbit, where sunlight gets too dim for solar cells to be efficient. The RTGs used by Ulysses and Galileo are strong enough, in theory, to survive any explosion the Shuttle system might undergo. They have been tested with five to eleven times the "overpressures" believed to have been generated by the Challenger explosion. But it has occurred to some engineers that if the Centaur exploded while the Shuttle was on the pad, it could throw debris into the RTGs or throw the RTGs against the Shuttle or launch pad structures, possibly breaking them open and spreading plutonium around.

On March 17, the Department of Energy declassified its estimates of the cost of such an accident. Under certain con-

Shuttle Payload Schedules Before and After the Challenger Accident



Source: NASA and the Congressional Budget Office

ditions, 386 square miles might be contaminated; over a fifty-year period, an extra forty-three cancer deaths could be caused. This has not been a concern in the past because the RTGs were mounted on top of the rockets. Any explosion would throw them up and away and the danger of releasing plutonium would be very slight.

Although Ulysses is small and rugged enough to possibly be launched on an expendable vehicle, the only American expendable launch vehicle (ELV) powerful enough to do the job is the Air Force's new Titan-34D7 with a Centaur upper stage, which won't be available until 1990. Ian Pryke, the European Space Agency's Washington representative, said "we cannot launch Ulysses on Ariane without developing an upper stage," which, he added, would take too long to complete. Jacqueline Schenkel of Ariane's marketing company, Arianespace, agrees, saying there is "absolutely no way" her company could launch Ulysses.

Mission Options and Compromises

In addition to sharing Ulysses' problems with the RTGs, Galileo cannot be carried aloft on any currently designed expendable launch vehicle. This giant spacecraft is simply too close to the upper limits of even Shuttle/Centaur performance.

A member of NASA's Jet Propulsion Laboratory management, who spoke to ASTRONOMY on the condition he not be identified, said June 1987 is a slightly better launch opportunity to Jupiter than May 1986 would have been because of a more advantageous planet alignment. Consequently, less propulsive power is needed. This delay could relieve some of the weight pressure on the Galileo program, but the improvement is not enough to add an extra orbit for additional scientific study at Jupiter. He also said this factor will have little impact on the Ulysses program since that spacecraft was not pushing the Shuttle/Centaur weight and capacity limits as much as Galileo.

Bob Mitchell, Galileo's navigation team chief, says that although the tour of Jupiter's Galilean satellites would have to be changed to accommodate a 1987 launch, by varying Galileo's arrival time at Jupiter a wide variety of tours become possible.

Especially critical to the mission is the location of Io. The most volcanically active body so far discovered in the solar system, this closest major moon to Jupiter is probably the most interesting of all the Galilean satellites. Yet only a single flyby is possible before Galileo must raise its orbit to avoid damage from the worst of Jupiter's intense radiation belts. This navigation problem is made even more complex because, during that same first approach to Jupiter, the orbiter must receive and relay to Earth information beamed up by the previously released probe deep in Jupiter's atmosphere while slowing itself into orbit around Jupiter. Fortunately, Io's period is only 1.7 Earth days, which provides plenty of opportunities for Galileo to drop its probe into Jupiter's atmosphere and then conduct a single flyby of Io.

An asteroid flyby on the way to Jupiter should still be possible, according to Mitchell, but "the likelihood of finding one as big and exciting as Amphitrite [would have been] is remote." He agrees with Meeks in expressing concern about the longevity of RTG power if Galileo's launch is delayed beyond the June 1987 window, adding that RTGs are both hard to come by and take a long time to replace; but he did not seem particularly worried about equipment wearing out.

As for missions scheduled for the latter part of this decade, project managers are still adhering to the deadlines and schedules determined before the Challenger accident, though they express concern about possible future conflicts. John Gerpheide, the Magellan Venus Radar Mapper's project manager, said his program is proceeding toward its previously planned April 1988 launch. However, he foresees "a tremendous battle" over who gets to use the limited Shuttle payload space. Magellan could be launched atop an expendable Titan-34D7, but again, these launch vehicles won't be ready in time.

Nonetheless, the mission itself is continuing final design work. Most subsystems are to be delivered late this year, followed immediately by testing and then build up of the spacecraft. Final

Cost/Payload Comparison

Shuttle vs. Complementary Expendable Launch Vehicle

Space Shuttle

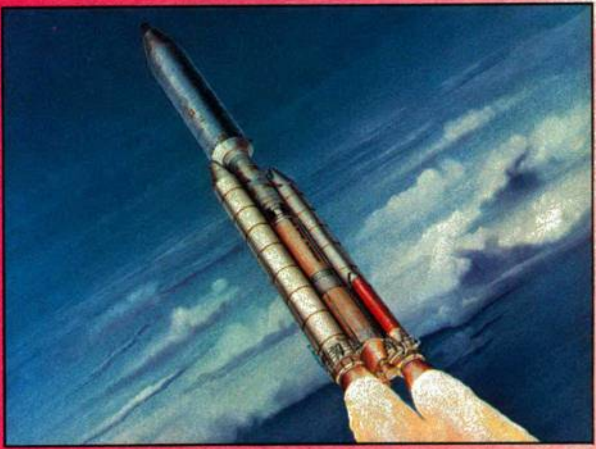
Payload capacity: 29,000 kilograms for low-Earth orbit

Total replacement cost (not amortized): $2.1 billion

Per-flight cost based on annual "operational costs" (launch and flight support plus expendable materials used in a typical flight) divided by the number of missions per year (1987): $180 million*

****Roughly 11 percent of this figure represents the costs of equipment upgrades and maintenance.***

Source: NASA and Martin Marietta Aerospace



Titan 34D-7

(currently in development)

Payload capacity less the Centaur upper stage: 18,180 kilograms for low-Earth orbit; 4,545 kilograms for geosynchronous orbit. With Centaur upper stage: same payload maximum as Shuttle.

Total cost of development (10 rockets produced): $2.1 billion

Per-flight cost based on two flights per year and less the Centaur upper stage hardware: $98 million

Launch operations: $24 million

Total: $122 million

Per-flight total based on two flights per year including Centaur upper stage: $200 - $300 million

assembly of the Radar flight model is to begin in October for delivery in mid-1987.

The next planetary mission NASA wants to get started is the Comet Rendezvous and Asteroid Flyby (CRAF). A source at JPL said this mission is still sufficiently far down the road that he did not expect it to be affected by the Challenger accident.

All this speculation is fine *if* the Shuttle is flying again within the year. The CBO analyst who released the Shuttle report to ASTRONOMY said NASA management is, for planning purposes anyway, assuming a first launch in March 1987, having concluded that any attempt at launching earlier would be unrealistic. He considered that date "mildly optimistic." As the extent of the necessary Shuttle modifications becomes clear — not just those to correct the solid rocket boosters but other problems as well — some officials are speculating that it will be eighteen to twenty-four months before Shuttle launches resume.

The CBO report adds that even when the Shuttle is flying again, NASA's current post-accident launch plans "could be too optimistic. [NASA] projects fourteen shuttle flights in 1988, a substantially greater number than the system has ever produced in [any previous] twelve-month period. In the twelve months before Flight 61C, the last successful flight . . . the Shuttle flew only nine times."

Future Choices Facing the Space Program

An accident that many saw as inevitable has thrown the entire American space program into utter confusion and is likely to delay space exploration for at least the remainder of the decade. Considering all their needs, it seems very unlikely that any of the previously mentioned missions can be flown in their present form, much less launched at the presently anticipated dates.

Many rocket engineers argue that no manned vehicle should ever have used solid rocket boosters (SRBs) which, although reliable, are inherently dangerous because they cannot be controlled in any way that is not previously programmed during manufacture. NASA has always admitted that if anything ever went wrong with an SRB, the vehicle and crew would almost certainly be lost. In fact, many engineers seem surprised the Shuttle SRBs performed as well as they did — most expected an SRB burn-through to result in its exploding on the pad. Nonetheless, Ian Pryke of the European Space Agency says they are still planning to use SRBs on the Ariane 5, which is to launch the French Hermes mini-shuttle (see "Europe's Place in Space: Number Three and Growing," May 1986).

Meanwhile, planetary scientists are reminding us of their opposition to total reliance on the Shuttle. They have long argued that expendable vehicles are sufficient to launch missions to the planets and that the Shuttle's cost has cut into planetary exploration.

The military, in a rather odd coalition with planetary scientists, tells us we should never have depended entirely on any single launch vehicle. But from the beginning, NASA officials decided to rely entirely on the Shuttle, with an initial plan to build ten or more orbiters. When it proved politically impossible to procure enough orbiters to make the Shuttle a viable "airline," NASA continued to insist that its four-orbiter fleet comprise the nation's entire launch capacity. Even if sufficient orbiters had been built, many have pointed out that it only took the loss of one orbiter to ground the entire fleet, and that there should have been a vehicle completely independent of Shuttle technology.

Louis Friedman, planetary scientist and director of the Planetary Society, believes the Challenger accident will cause a long-term re-thinking of NASA goals. NASA must have both automated and human launch systems, with manned vehicles used only when a human presence is necessary. He believes both the cost and the public reaction to the disaster make a solely human launch system impossible. This applies to any second-generation shuttle, like the recently begun transatmospheric vehicle project, because according to Friedman, at least 75 percent of all payloads do not require a human presence.

But the CBO report emphatically disagrees with this. The report states that "returning the Shuttle system to safe operation, procuring a fourth orbiter, and establishing a back-up expendable launch vehicle program . . . together with a more conservative and probably more costly operation mode for the Shuttle system, [might result in] additions to the NASA budget [that] could approach $1 billion annually over the next five years." (A new orbiter alone would require that $263 million be added to the 1986 budget and $702 million to the 1987 budget, according to NASA estimates.)

Nonetheless, the CBO report holds that "the amortized cost of a new Shuttle orbiter is likely to be lower than that of an expendable launch vehicle program of equal capacity. . . . An expendable launch vehicle program to fill the deficiency left by the loss of an orbiter could be at least as expensive [as replacing Challenger]. For example, the Air Force recently purchased ten [Titan-34D7] rockets for $2 billion, roughly the cost of one Shuttle."

Friedman is also critical of the "timed commitment for a permanent manned presence in space. I think [the Space Station program] should be re-examined and re-defined to more usefully support what we should be doing in space. [This re-designed Space Station] would include robotic and manned systems." Human systems, Friedman adds, should be strictly limited to those that require a human presence, such as a human mission to Mars. Friedman believes the Challenger accident need not be a major setback to the human exploration of Mars, although he emphasized it will not help it. But "to the extent this will make people think about what they want, [these events] could be constructive."

The biggest losers in any retreat from human spaceflight engendered by Challenger's loss will be the small-scale experiments operated by scientists with limited funding. Even before the Challenger accident, the locker space on the Shuttle's mid-deck used for small, self-contained experiments was oversubscribed for years into the future, to the extent that a company called Spacehab is designing a module to increase room for these experiments. Likewise, small "getaway special" payloads exposed in the payload bay had attracted unexpected commercial and scientific interest. These cannot be launched economically on expendable boosters. Similar small-scale programs would benefit even more from the Space Station.

Larger scale commercial endeavors, such as McDonnell Douglas' electrophoresis project to make ultra-pure medicines in space, are even more dependent on the Shuttle and Space Station. Satellite repair, which promises to drastically cut the cost of both commercial and scientific satellites, is only just getting underway. Space salvage of old satellites is another commercial activity some companies are considering. Automated launch vehicles are appropriate to none of these. And to the extent that it damages commercial endeavors in space, any retreat from human spaceflight will increase the costs of reaching near-Earth orbit for both industrialists and scientists.

Friedman reminds us that even a one-year delay in planetary missions will increase costs dramatically, reducing money available for future activities. The scientific and engineering teams that run these missions must be kept together — and paid — whether the mission is flying or not. Friedman believes that unless there is a conscious decision on the part of the President to support continued planetary exploration, the increased costs caused by the Shuttle explosion and its subsequent modification and replacement will virtually rule out new planetary and space science missions for the foreseeable future.

Donald F. Robertson is a freelance writer currently working on a book with Tim Kyger on the political history behind the decision to use solid rocket boosters on the Space Shuttle.

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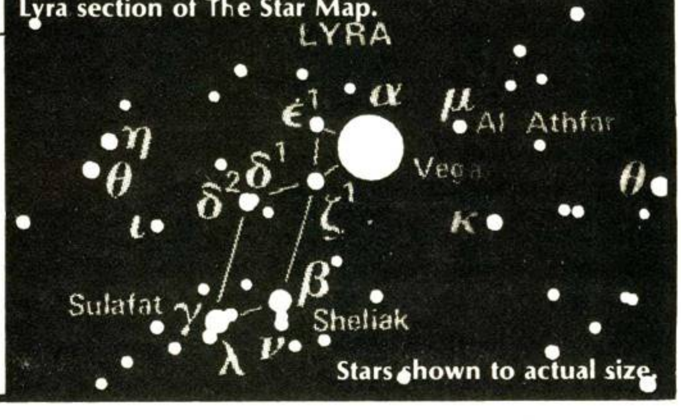

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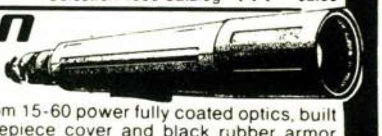

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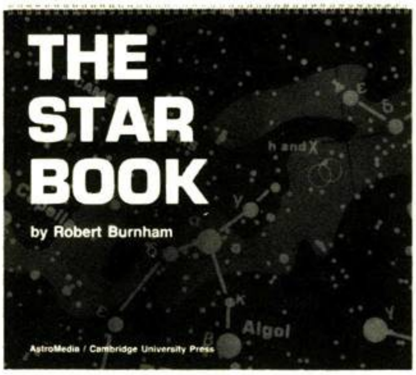

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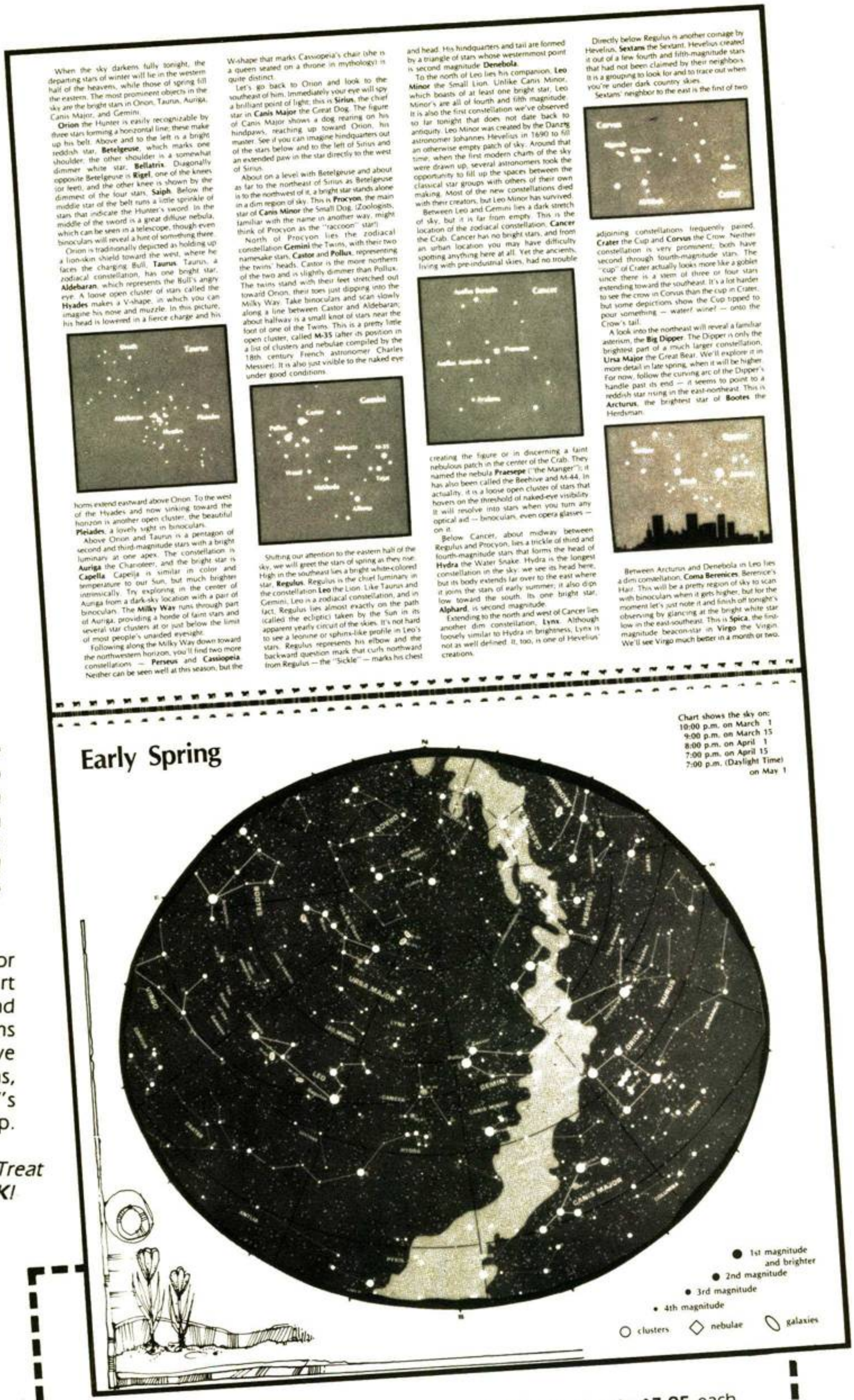

When the sky darkens fully tonight, the departing stars of winter will lie in the western half of the heavens, while those of spring fill the eastern. The most prominent objects in the sky are the bright stars in Orion, Taurus, Auriga, Canis Major, and Gemini.

Orion the Hunter is easily recognizable by three stars forming a horizontal line; these make up his belt. Above and to the left is a bright reddish star, **Betelgeuse**, which marks one shoulder; the other shoulder is a somewhat dimmer white star, **Bellatrix**. Diagonally opposite Betelgeuse is **Rigel**, one of the knees (or feet), and the other knee is shown by the dimmest of the four stars, **Saiph**. Below the middle star of the belt runs a little sprinkle of stars that indicate the Hunter's sword. In the middle of the sword is a great diffuse nebula, which can be seen in a telescope, though even binoculars will reveal a hint of something there.

Orion is traditionally depicted as holding up a lion-skin shield toward the west, where he faces the charging Bull, **Taurus**. Taurus, a zodiacal constellation, has one bright star, **Aldebaran**, which represents the Bull's angry eye. A loose open cluster of stars called the **Hyades** makes a V-shape, in which you can imagine his nose and muzzle. In this picture, his head is lowered in a fierce charge and his horns extend eastward above Orion. To the west of the Hyades and now sinking toward the horizon is another open cluster, the beautiful **Pleiades**, a lovely sight in binoculars.

Above Orion and Taurus is a pentagon of second and third-magnitude stars with a bright luminary at one apex. The constellation is **Auriga** the Charioteer, and the bright star is **Capella**. Capella is similar in color and temperature to our Sun, but much brighter intrinsically. Try exploring in the center of Auriga from a dark-sky location with a pair of binoculars. The **Milky Way** runs through part of Auriga, providing a horde of faint stars and several star clusters at or just below the limit of most people's unaided eyesight.

Following along the Milky Way down toward the northwestern horizon, you'll find two more constellations — **Perseus** and **Cassiopeia**. Neither can be seen well at this season, but the W-shape that marks Cassiopeia's chair (she is a queen seated on a throne in mythology) is quite distinct.

Let's go back to Orion and look to the southeast of him. Immediately your eye will spy a brilliant point of light; this is **Sirius**, the chief star in **Canis Major** the Great Dog. The figure of Canis Major shows a dog rearing on his hindpaws, reaching up toward Orion, his master. See if you can imagine hindquarters out of the stars below and to the left of Sirius and an extended paw in the star directly to the west of Sirius.

About on a level with Betelgeuse and about as far to the northeast of Sirius as Betelgeuse is to the northwest of it, a bright star stands alone in a dim region of sky. This is **Procyon**, the main star of **Canis Minor** the Small Dog. (Zoologists, familiar with the name in another way, might think of Procyon as the "raccoon" star!)

North of Procyon lies the zodiacal constellation **Gemini** the Twins, with their two namesake stars, **Castor** and **Pollux**, representing the twins' heads. Castor is the more northern of the two and is slightly dimmer than Pollux. The twins stand with their feet stretched out toward Orion, their toes just dipping into the Milky Way. Take binoculars and scan slowly along a line between Castor and Aldebaran; about halfway is a small knot of stars near the foot of one of the Twins. This is a pretty little open cluster, called **M-35** (after its position in a list of clusters and nebulae compiled by the 18th century French astronomer Charles Messier). It is also just visible to the naked eye under good conditions.

Shifting our attention to the eastern half of the sky, we will greet the stars of spring as they rise. High in the southeast lies a bright white-colored star, **Regulus**. Regulus is the chief luminary in the constellation **Leo** the Lion. Like Taurus and Gemini, Leo is a zodiacal constellation, and in fact, Regulus lies almost exactly on the path (called the ecliptic) taken by the Sun in its apparent yearly circuit of the skies. It's not hard to see a leonine or sphinx-like profile in Leo's stars. Regulus represents his elbow and the backward question mark that curls northward from Regulus — the "Sickle" — marks his chest and head. His hindquarters and tail are formed by a triangle of stars whose westernmost point is second magnitude **Denebola**.

To the north of Leo lies his companion, **Leo Minor** the Small Lion. Unlike Canis Minor, which boasts of at least one bright star, Leo Minor's are all of fourth and fifth magnitude. It is also the first constellation we've observed so far tonight that does not date back to antiquity. Leo Minor was created by the Danzig astronomer Johannes Hevelius in 1690 to fill an otherwise empty patch of sky. Around that time, when the first modern charts of the sky were drawn up, several astronomers took the opportunity to fill up the spaces between the classical star groups with others of their own making. Most of the new constellations died with their creators, but Leo Minor has survived.

Between Leo and Gemini lies a dark stretch of sky, but it is far from empty. This is the location of the zodiacal constellation **Cancer** the Crab. Cancer has no bright stars, and from an urban location you may have difficulty spotting anything here at all. Yet the ancients, living with pre-industrial skies, had no trouble creating the figure or in discerning a faint nebulous patch in the center of the Crab. They named the nebula **Praesepe** ("the Manger"); it has also been called the Beehive and M-44. In actuality, it is a loose open cluster of stars that hovers on the threshold of naked-eye visibility. It will resolve into stars when you turn any optical aid — binoculars, even opera glasses — on it.

Below Cancer, about midway between Regulus and Procyon, lies a trickle of third and fourth-magnitude stars that forms the head of **Hydra** the Water Snake. Hydra is the longest constellation in the sky: we see its head here, but its body extends far over to the east where it joins the stars of early summer; it also dips low toward the south. Its one bright star, **Alphard**, is second magnitude.

Extending to the north and west of Cancer lies another dim constellation, **Lynx**. Although loosely similar to Hydra in brightness, Lynx is not as well defined. It, too, is one of Hevelius' creations.

Directly below Regulus is another coinage by Hevelius, **Sextans** the Sextant. Hevelius created it out of a few fourth and fifth-magnitude stars that had not been claimed by their neighbors. It is a grouping to look for and to trace out when you're under dark country skies.

Sextans' neighbor to the east is the first of two adjoining constellations frequently paired, **Crater** the Cup and **Corvus** the Crow. Neither constellation is very prominent; both have second through fourth-magnitude stars. The "cup" of Crater actually looks more like a goblet since there is a stem of three or four stars extending toward the southeast. It's a lot harder to see the crow in Corvus than the cup in Crater, but some depictions show the Cup tipped to pour something — water? wine? — onto the Crow's tail.

A look into the northeast will reveal a familiar asterism, the **Big Dipper**. The Dipper is only the brightest part of a much larger constellation, **Ursa Major** the Great Bear. We'll explore it in more detail in late spring, when it will be higher. For now, follow the curving arc of the Dipper's handle past its end — it seems to point to a reddish star rising in the east-northeast. This is **Arcturus**, the brightest star of **Bootes** the Herdsman.

Between Arcturus and Denebola in Leo lies a dim constellation, **Coma Berenices**, Berenice's Hair. This will be a pretty region of sky to scan with binoculars when it gets higher, but for the moment let's just note it and finish off tonight's observing by glancing at the bright white star low in the east-southeast. This is **Spica**, the first-magnitude beacon-star in **Virgo** the Virgin. We'll see Virgo much better in a month or two.

Early Spring

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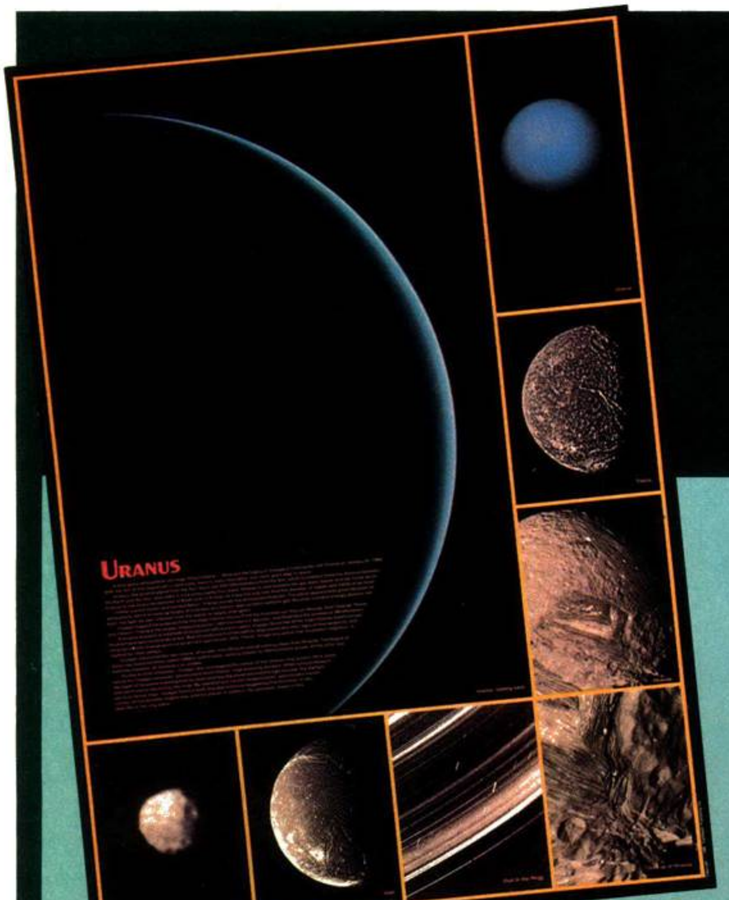

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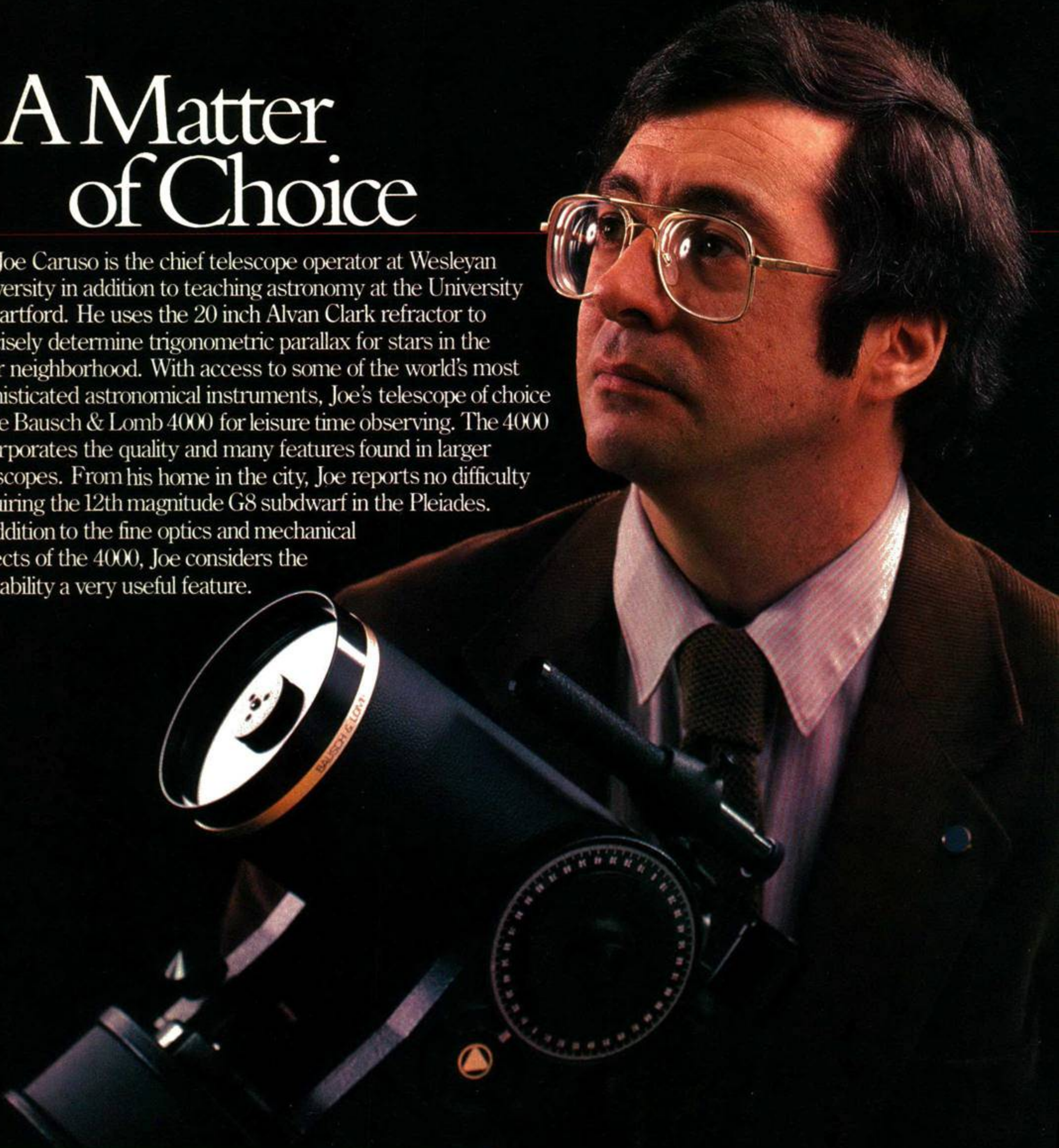

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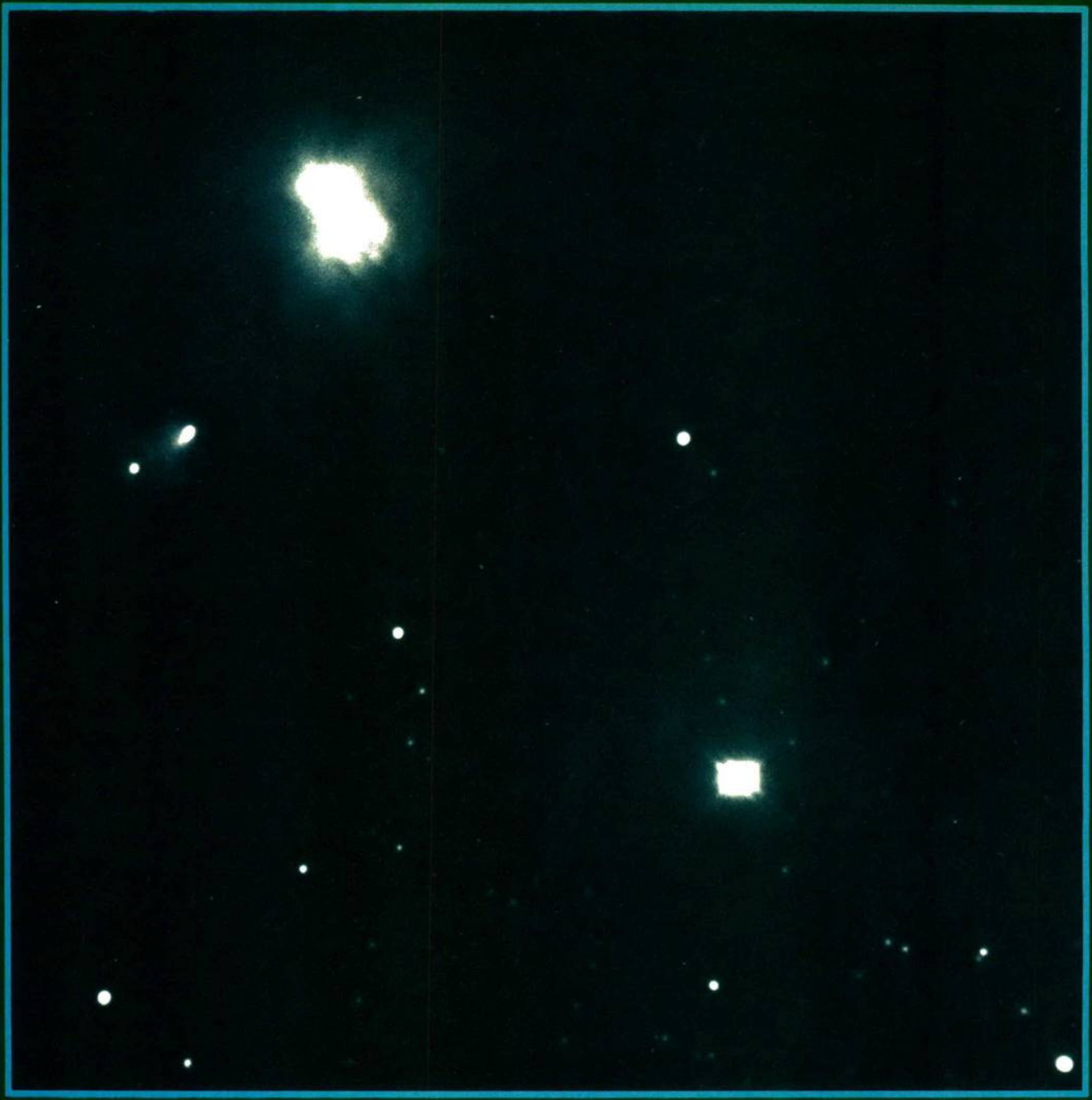
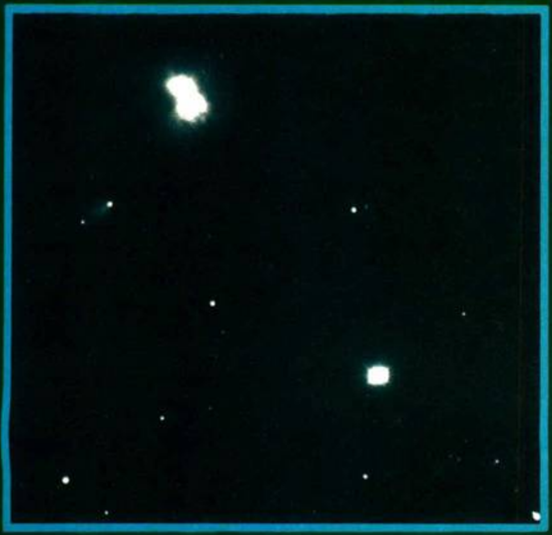




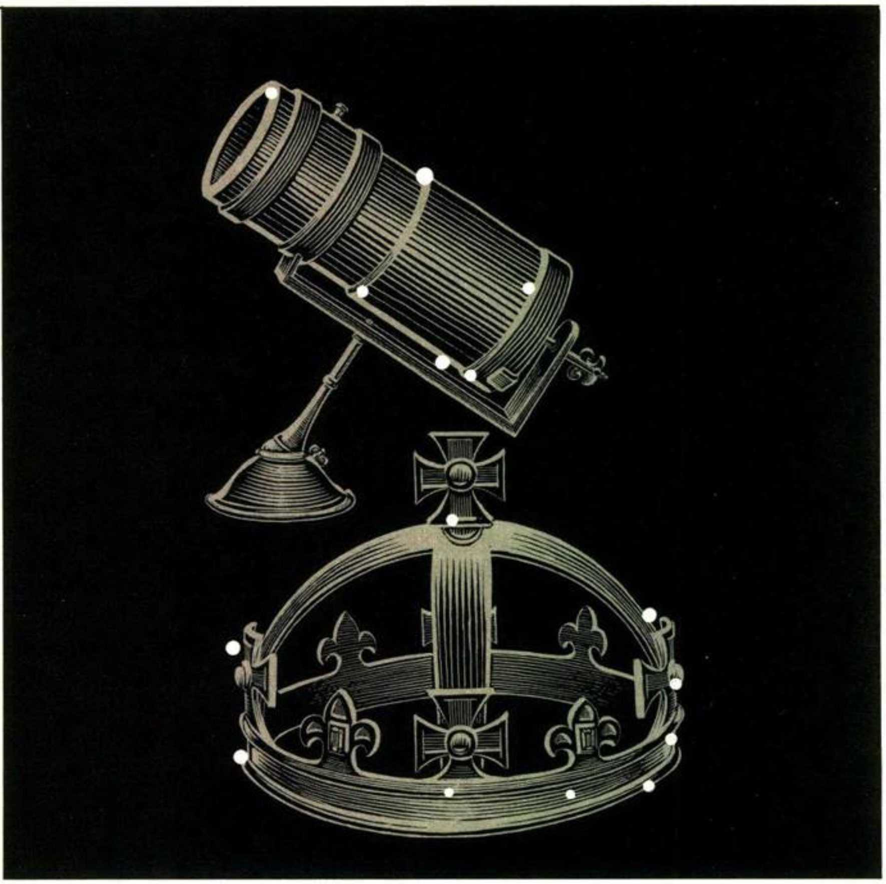
This pair of photographs shows the changing brightness and dimensions of the nebulae designated NGC-6726/7 and NGC-6729. The area photographed on June 14, 1917 (above) shows NGC-6726/7 as a double knot of bright nebulosity and NGC-6729 as a comet-shaped blob; the same area photographed on July 11, 1936, reveals a different structure in the nebulae. Both photographs were made by Carl O. Lampland using the 13.1-inch astrographic camera at Lowell Observatory in Flagstaff, Arizona. Lowell Observatory photos.

Corona Australis

CrA
Coronae Australis

Telescopium

Tel
Telescopii


Keith Ward

Ten degrees below the bright Teapot of Sagittarius lies the diminutive constellation **Corona Australis** the Southern Crown. Its dim stars form a graceful arc that grazes the treetops for most Northern Hemisphere viewers but is sufficiently high for observing by telescope owners south of about 30° north latitude. To its south lies the even more inconspicuous constellation **Telescopium** the Telescope. It is difficult to see north of about 20° north latitude.

Despite their southerly declinations, these two constellations offer a handful of bright deep-sky objects for viewers with medium- or large-size telescopes. Corona Australis holds several fine globular clusters and an unusual complex of emission and reflection nebulosity. Telescopium, which lies farther away from the plane of the Milky Way, contains a number of elliptical and spiral galaxies.

The best globular in Corona Australis is **NGC-6541**, a magnitude 6.6 object that lies within the same low-power field as a 6th-magnitude star. To locate this group of stars, start at Shaula (Lambda [λ] Scorpii), the bright star marking the Scorpion's stinger. Now move southeast to the equally bright Kappa (κ) Scorpii, another star in the tail of Scorpius. Continuing in a straight line, pass by the wide unequal double formed by Iota^1 (ι^1) and Iota^2 (ι^2) Scorpii and continue 3° to a lone 6th-magnitude sun. Then move another 3° along the line to a second 6th-magnitude star; you're now aimed at the field containing NGC-6541.

NGC-6541 spans 13.1′, although in binoculars and finderscopes you'll probably see it as a glow some 3′ in diameter. Small telescopes reveal a nebulous disk measuring 5′ across located in a rich starry field. An 8-inch telescope at high power partially resolves this globular's faint outer edge into stars while the nucleus remains bright and unresolved.

About 2° southwest is a 6th-magnitude star that forms an isosceles triangle with the star accompanying NGC-6541 and the equally bright star located 3° southeast of the Iota^{1,2} pair. Within the same low-power field as this third 6th-magnitude star is another globular, **NGC-6496**. (The star is actually in Scorpius, but NGC-6496 lies just within the border of Corona Australis.) This cluster is far smaller and dimmer than its neighbor but is nevertheless a fine sight for small telescope users.

Shining at about magnitude 9, NGC-6496 covers nearly 7′ of sky. This globular is visible as a hazy patch of light in binoculars under a dark sky, though it may be difficult to see when it lies near the horizon if there is even slight light pollution or an unsteady atmosphere. A 6-inch telescope typically reveals NGC-6496 as a milky glow some 3′ across peppered with pinpoint stars. The surrounding field is so rich that these stars are likely foreground Milky Way stars. NGC-6496's rather great distance of 19.0 kiloparsecs makes it doubtful that such a small instrument could resolve the cluster's constituent stars.

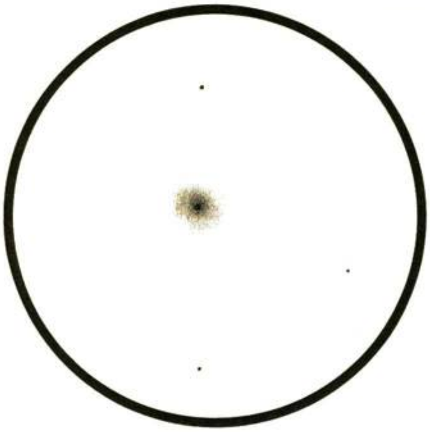
Some 9° southeast of these two clusters lies Telescopium's sole bright globular, **NGC-6584**. This cluster appears remarkably similar to NGC-6496, measuring 7.9′ in diameter and glowing at around 9th magnitude. A 4-inch scope shows NGC-6584 as a featureless disk of gray light some 3′ across, and an 8-incher resolves the cluster's edge into a sprinkling of faint stars. Several lanes of these resolved stars emanating outward from the cluster are reminiscent of the much larger and brighter rows of stars visible in M-13, the Hercules Cluster.

Corona Australis' three brightest stars, all shining at 4th magnitude, form the brightest segment of the constellation's unmistakable arc. Alpha (α) CrA, Beta (β) CrA, and the wide double Gamma (γ) CrA are also markers for finding one of the strangest fields of nebulosity in this part of the sky. Set your telescope cross hairs 1° west of Gamma and you'll come upon the 7th-magnitude double star Epsilon (ε) CrA. To the northeast in this same low-power field is the complex of nebulosity dubbed **NGC-6726/7** and **NGC-6729**. NGC-6726/7, a double nebulosity that earned two separate NGC numbers, is a reflection nebula shaped like a figure eight some 2′ in extent. The nebula's southwestern section contains a 7th-magnitude pure white star and the northeastern part holds the erratic variable star **TY Coronae Australis**. This unusual star fluctuates irregularly between magnitudes 8.8 and 12.6; its magnitude can be checked against that of the 7th-magnitude star located nearby.

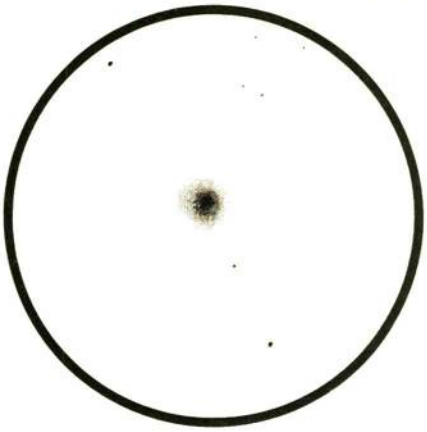
About 4.7′ southeast of the double nebula is the even stranger nebulosity NGC-6729. This patch of gray light is 1′

For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

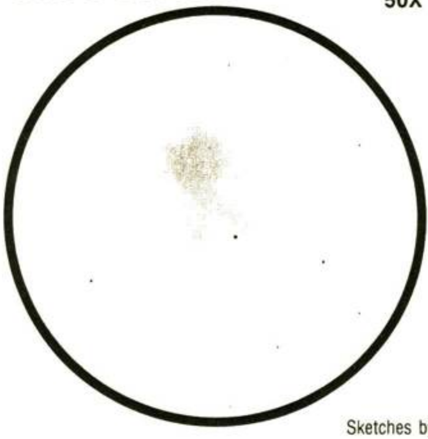
NGC-6496 8-inch f/10 SCT 50X



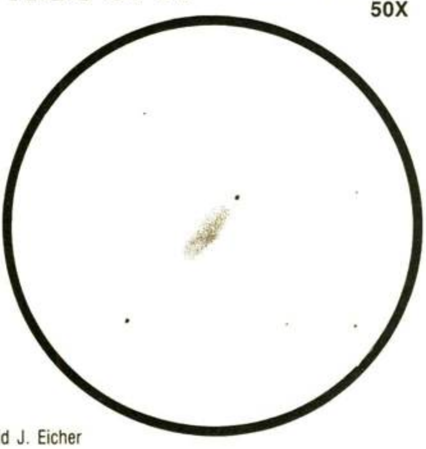
NGC-6541 8-inch f/10 SCT 50X



NGC-6726/7 8-inch f/10 SCT 50X



NGC-6729 8-inch f/10 SCT 50X



Sketches by David J. Eicher

long and appears as a tiny comet complete with a fuzzy tail. Embedded within this object is the bizarre nebular variable R Coronae Australis. This star's fluctuations in light change the visible size of the nebulosity, much like Hubble's Variable Nebula in Monoceros. The star nominally shines at 12th magnitude but can flare to 10th in just a few days, noticeably changing the nebula's shape. Inside the "tail" of this emission and reflection nebulosity is yet another variable, T Coronae Australis. This and another star in the field, S Coronae Australis, fluctuate much like R CrA but are about two magnitudes fainter. (Less than a degree north of this nebulosity lies the globular NGC-6723, across the border in Sagittarius.)

Corona Australis and Telescopium each hold one bright planetary nebula. **IC 1297** lies wedged between 7th- and 8th-magnitude stars 2° southeast of Beta CrA. This nebula appears as a pale blue disk 7" across in a field swimming with stars. It shows no detail within the disk and reveals no central star to backyard telescopes. **IC 4699** lies equidistant between the stars Alpha and Epsilon Telescopii and is visible in small scopes as a dim circular nebulosity some 10" across. An 11th-magnitude star lies about 1′ north of the disk, and there is a faint pair of stars some 1′ to the southwest.

Telescopium's oddest star is **RR Telescopii**, a variable found in the southeastern corner of the constellation a mere 3° northwest of Alpha Pavonis. This star is an extreme case of a "slow nova," with a freakish history of behavior. During the 1930s, the star varied between magnitudes 12 and 15 over a period of 387 days, but in the early 1940s it fell to several minima of magnitude 16.5. In 1944, RR Tel went nova and exploded in brightness to magnitude 7, remaining that bright for a number of years. By 1951 the star had faded to 8th magnitude and it has continued fading since.

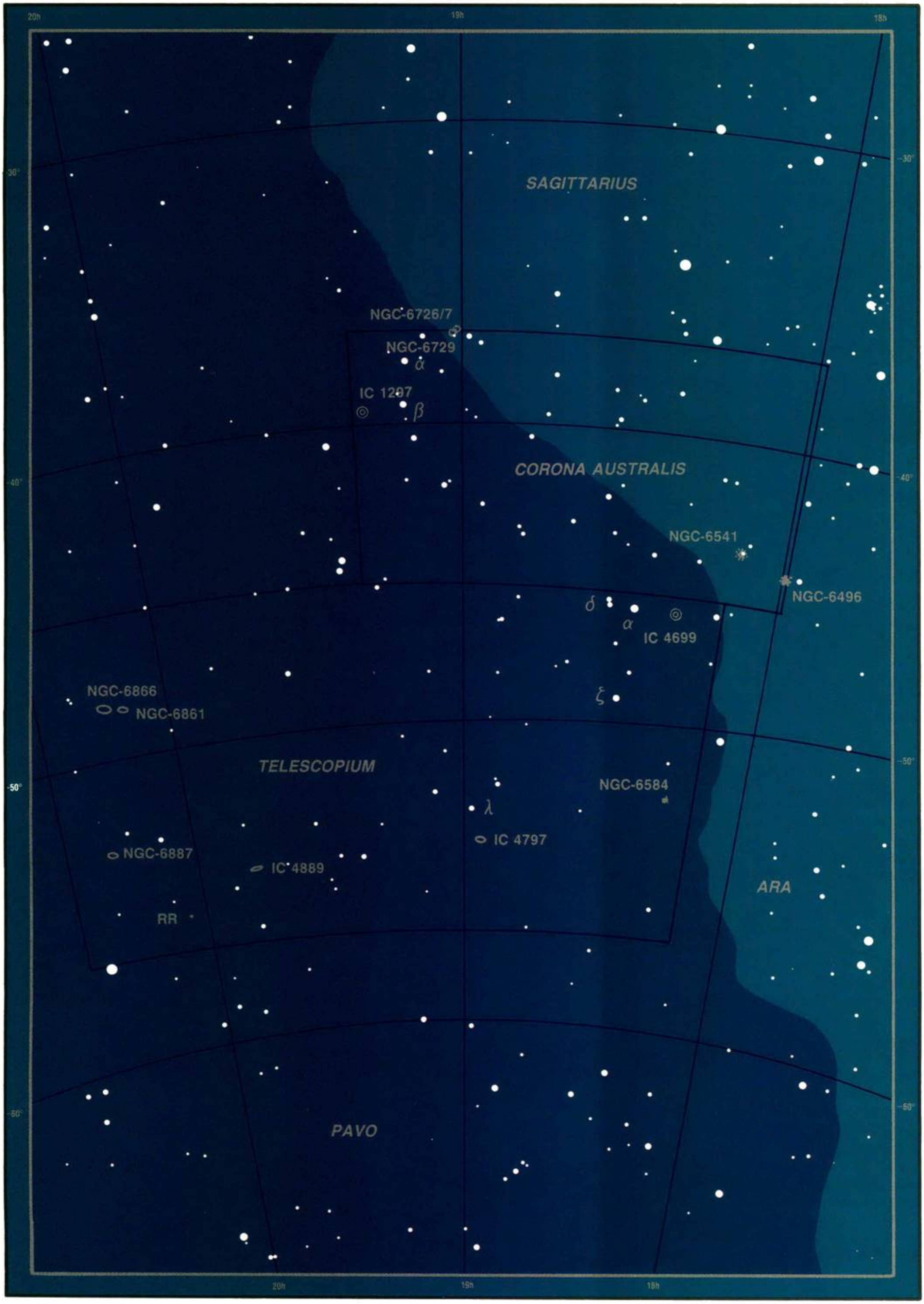
A number of bright galaxies lie scattered across Telescopium. **IC 4797** is an 11th-magnitude elliptical galaxy found 2° south of Lambda Tel. It measures 2.8′ x 1.3′ across and appears as an oval patch of light in 4-inch or larger scopes. **IC 4889** lies 7° due east of IC 4797 and appears quite similar. It, too, is elliptical; its magnitude is 12.4 in blue light and its dimensions are 2.6′ x 1.4′. **NGC-6861** and **NGC-6868** lie in the same wide telescopic field in the northeastern part of Telescopium. The former is an 11th-magnitude lenticular galaxy; the latter is an elliptical of comparable size and brightness. **NGC-6887**, 5° southeast of the NGC-6861/NGC-6868 pair, is a relatively large, faint spiral appearing in small scopes as a hazy mass of milky light.

Object	M#	Type	R.A. (2000)	Dec.	Mag.	Size/Sep./Per.	H
NGC-6496		●	17h 59.0m	−44°16′	9.2:	6.9′	
NGC-6541		●	18h 08.0m	−43°42′	6.6	13.1′	
NGC-6584		●	18h 18.6m	−52°13′	9.2:	7.9′	
IC 4699		■	18h 18.6m	−45°59′	11.9_P	10″	
IC 4797		0	18h 56.5m	−54°18′	11.39	2.8′x1.3′	E5
NGC-6726-7		☐R	19h 01.7m	−36°53′	—	2′x2′	
TY CrA		IV	19h 01.7m	−36°53′	8.8↔12.6	irr.	
NGC-6729		☐ER	19h 01.9m	−36°57′	—	1′	
IC 1297		■	19h 17.4m	−39°37′	—	7″	
IC 4889		0	19h 45.3m	−54°20′	12.4_B	2.6′x1.4′	E5
RR Tel		IV	20h 04.2m	−55°43′	6.5↔16.5	irr.	
NGC-6861		§L	20h 07.3m	−48°22′	11.1	2.7′x1.4′	S0
NGC-6868		0	20h 09.9m	−48°23′	12.0_B	2.7′x2.2′	E2
NGC-6887		§	20h 17.2m	−52°47′	12.5_B	4.1′x1.7′	Sb⁺:

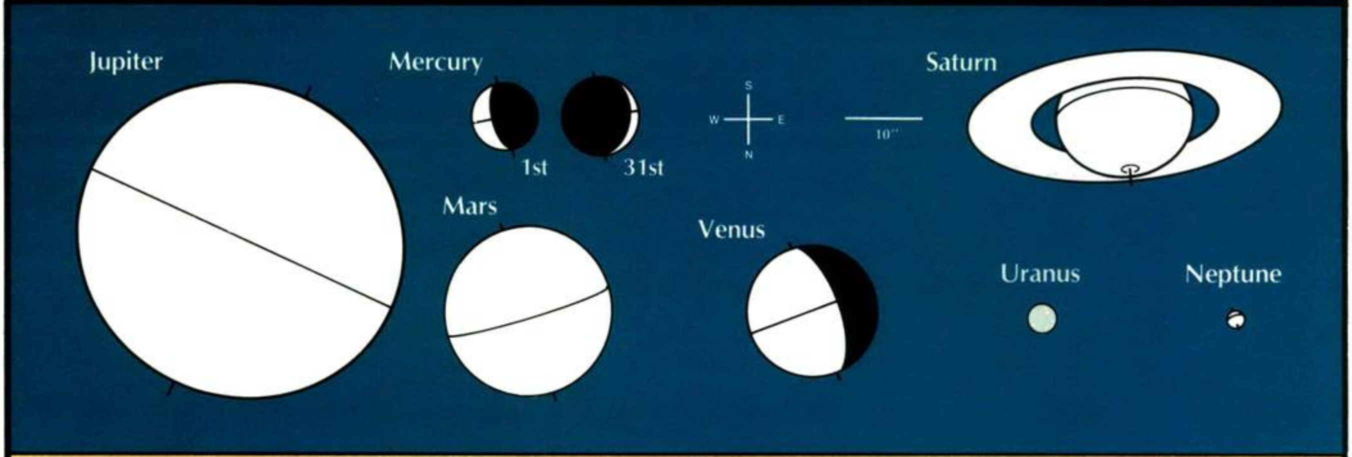
H = Hubble classification type for galaxies

subscript "P" denotes photographic magnitude; subscript "B" denotes blue magnitude.

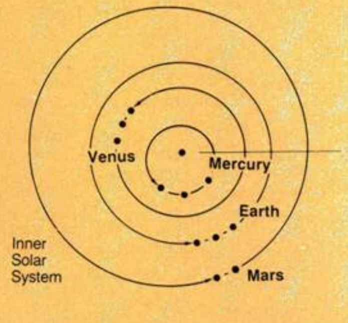
IV	*Irregular Variable*
●	*Globular Cluster*
■	*Planetary Nebula*
☐ER	*Emission/Reflection Nebula*
☐R	*Reflection Nebula*
0	*Elliptical Galaxy*
§L	*Lenticular Galaxy*
§	*Spiral Galaxy*

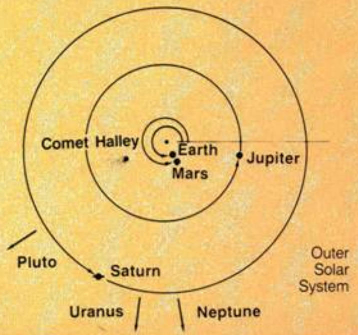

20h
19h
18h
30°
-30°
SAGITTARIUS
NGC-6726/7
NGC-6729
α
IC 1297
β
-40°
-40°
CORONA AUSTRALIS
NGC-6541
NGC-6496
δ
α
IC 4699
ζ
NGC-6866
NGC-6861
TELESCOPIUM
-50°
-50°
NGC-6584
λ
IC 4797
NGC-6887
IC 4889
ARA
RR
-60°
-60°
PAVO
20h
19h
18h

Planetary Data July 1986


Jupiter
Mercury
1st
31st
S
W
E
N
10''
Saturn
Mars
Venus
Uranus
Neptune

	Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Sun	Longitude: Heliocentric	Ecliptic	R.A. (2000.0)	Dec.
Sun	1	−26.7	31.5′	—	1.02	—	—	98°53.2′	6h 39.5m	23°08.0′
	15	−26.7	31.5′	—	1.02	—	—	112°14.4′	7h 36.9m	21°34.8′
	31	−26.7	31.6′	—	1.02	—	—	127°30.9′	8h 40.4m	18°20.9′
Mercury	1	0.9	9.0″	31%	0.75	0.46	236°19.2′	123°27.2′	8h 23.2m	18°44.8′
	15	2.9	11.3″	7%	0.59	0.46	275°07.6′	125°27.4′	8h 27.8m	15°01.5′
	31	2.8	10.3″	8%	0.65	0.40	326°18.2′	116°39.1′	7h 50.2m	16°42.8′
Venus	1	−4.0	14.8″	73%	1.13	0.72	200°03.4′	137°56.0′	9h 23.8m	17°11.0′
	15	−4.1	16.3″	68%	1.02	0.72	222°32.5′	153°55.9′	10h 25.4m	11°18.9′
	31	−4.1	18.6″	62%	0.90	0.73	248°03.8′	171°42.2′	11h 30.2m	3°39.4′
Mars	10	−2.6	23.0″	100%	0.41	1.42	287°33.0′	287°56.4′	19h 21.0m	−27°41.4′
	20	−2.6	23.1″	100%	0.40	1.41	293°35.0′	285°07.3′	19h 08.5m	−28°22.4′
Jupiter	15	−2.7	44.9″	99%	4.41	4.99	342°37.4′	353°00.0′	23h 36.5m	− 3°57.9′
Saturn	15	0.3	17.8″	100%	9.30	10.00	247°52.5′	243°41.6′	16h 08.2m	−19°00.7′
Uranus	15	5.5	3.9″	100%	18.29	19.15	260°46.4′	259°23.0′	17h 13.4m	−23°06.4′
Neptune	15	7.9	2.3″	100%	29.28	30.24	274°32.5′	274°09.1′	18h 17.8m	−22°16.5′
Pluto	15	13.7	0.1″	100%	29.49	29.72	216°32.1′	214°49.7′	14h 31.9m	2°35.2′

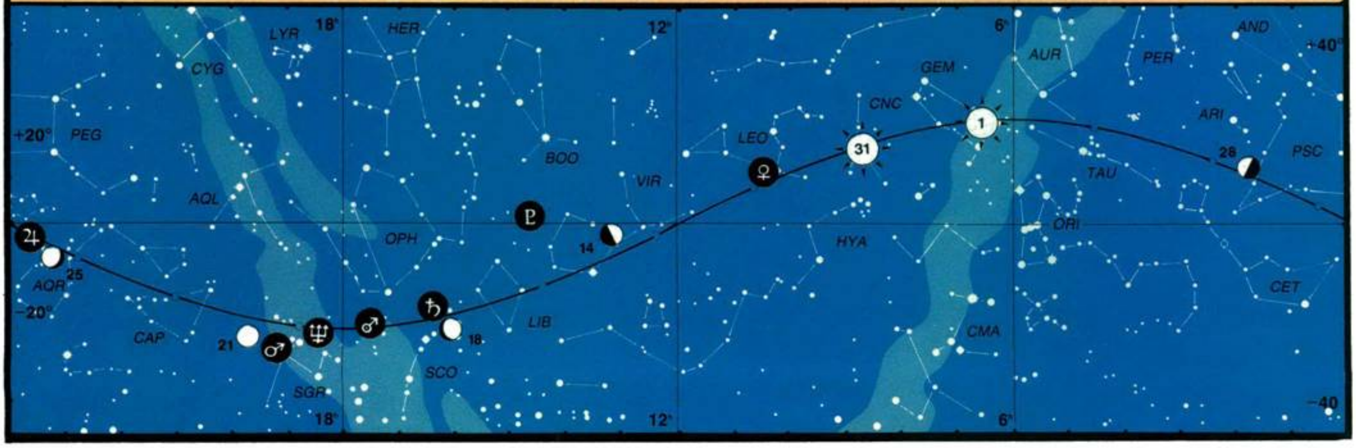

Venus
Mercury
Earth
Mars
Inner Solar System

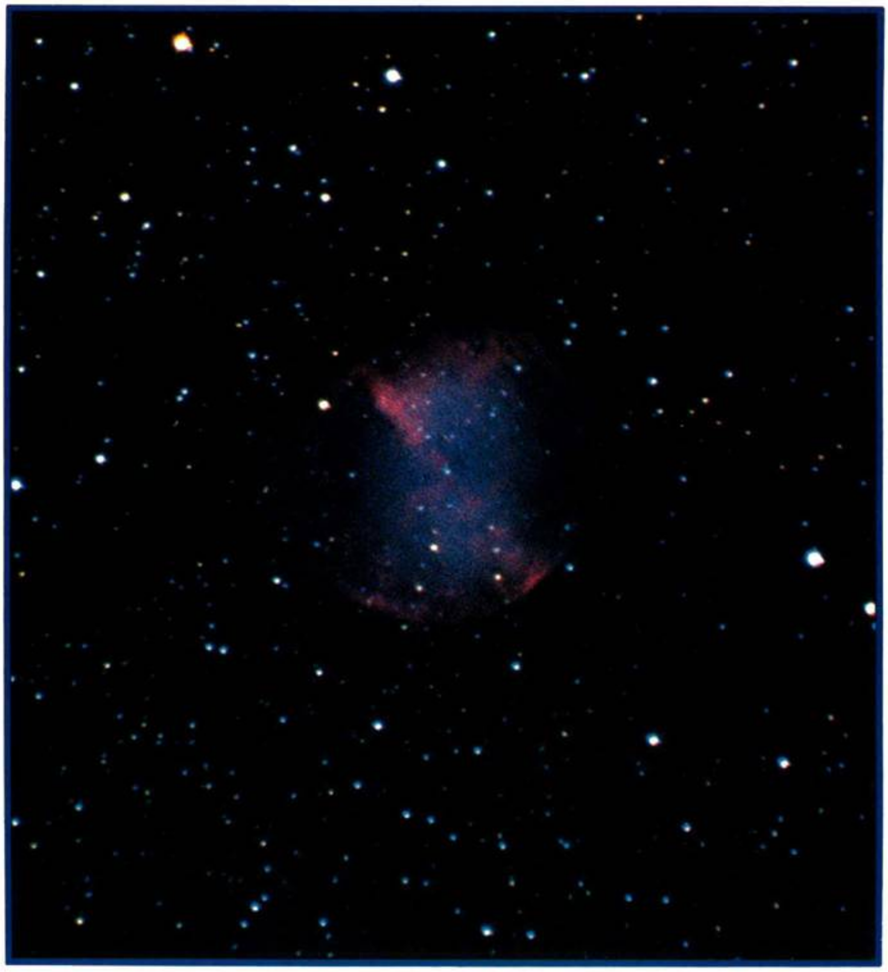

Comet Halley
Earth
Mars
Jupiter
Pluto
Saturn
Outer Solar System
Uranus
Neptune

Moon Data

New Moon. . . . . July 7 at 4h55m
First Quarter. . . . . July 14 at 20h10m
Full Moon. . . . . July 21 at 10h40m
Last Quarter. . . . . July 28 at 15h34m
New Moon. . . . . August 5 at 18h36m

Apogee: July 4 at 8h02m. . . . . . 406,103 km.
Perigee: July 19 at 19h31m. . . . 360,847 km.
Apogee: July 31 at 21h20m. . . . 405,166 km.


LYR
18h
HER
12h
6h
AND
+40°
CYG
GEM
AUR
PER
CNC
ARI
+20°
PEG
LEO
31
1
PSC
28
BOO
VIR
TAU
AQL
ORI
OPH
14
HYA
25
AQR
−20°
CET
CAP
21
18
LIB
CMA
SCO
SGR
18h
12h
6h
−40



One of the summer sky's grandest showpieces is the Dumbbell Nebula in Vulpecula, a planetary otherwise known as M-27. Its shape is obvious in a small telescope or even large binoculars. Photo by David Healy using a 14-inch f/6 SCT, hypersensitized Fujichrome 400 film developed as a negative, and a 40-minute exposure.

Mercury

Mercury will be visible but difficult to observe in the evening sky during early July. Only 6° high (45 minutes after sunset) on July 1, it will be lower and less visible each night thereafter, finally vanishing into the glow of sunset by about the 8th. The upcoming morning apparition in mid-August will be fairly good, however, and telescope owners may prefer to wait until then to view the planet.

Venus

This month finds Venus a little lower in the west each evening after sunset. Although Venus is becoming more difficult to observe, its brightness is actually increasing because the planet is overtaking the Earth in its path around the Sun. Besides brightening, Venus' disk is also growing larger while its phase is "flattening" more and more toward half-lit.

Moon

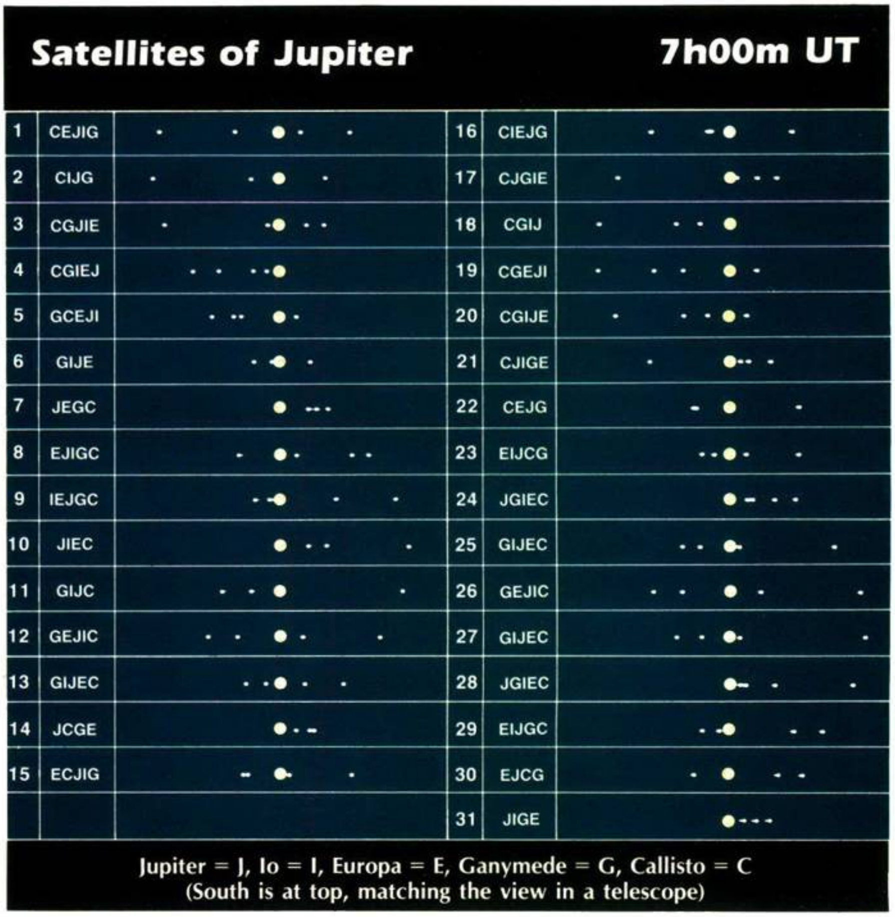
The lunar occultation of the double star Antares (Alpha [α] Scorpii) last May 24 was part of a series of Antares occultations that will continue until 1991, with the Moon covering up this bright star once every lunation. Bear in mind, however, that the Western Hemisphere will not be turned in the right direction at the moment of occultation for each event, so we won't be able to observe all of them.

The July occultation comes on the 18th and is very well-timed, being visible from nearly all of the continental United States and Canada. On the West Coast, the event will occur around 3h 30m UT; on the East Coast it will take place around 5h 00m. In North Central regions the event occurs sometime after 3h 00m.

Low-latitude observers in places such as Los Angeles and Miami may see a grazing occultation with the star nipping in and out of sight behind mountains along the Moon's southern limb. (Check with your local astronomy club to see if they are planning an expedition to the graze line.) Be sure to leave ample time before the event to set up your telescope for viewing.

Since the Moon's phase is about two days before Full, the star will disappear on the Moon's dark limb — an easy event to see. Its reappearance will occur on the bright limb anywhere from a few minutes (near the southern graze limit) to over an hour later (in northern latitudes).

Try timing Antares' disappearance and reappearance with a stopwatch and the U.S. Naval Observatory's phone-in time service, (900) 410-TIME. (The phone company's toll charge is 50¢ for the first minute.) Start the stopwatch when you



Jupiter = J, Io = I, Europa = E, Ganymede = G, Callisto = C
(South is at top, matching the view in a telescope)

observe the event and stop it when you hear the minute "beep" signal on the time service recording. Subtract the watch reading from that time to get the time when the event occurred. Send the results with your name, latitude, longitude, observing site elevation, and instrument data to the International Occultation Timing Association, 6 N. 106 White Oak Lane, St. Charles, IL 60174. (Enclose a self-addressed, stamped envelope or postcard if you want an acknowledgment.)

Mars

Although Mars reaches opposition to the Sun on July 10, it won't be closest to Earth until six days later. This happens because the orbits of Earth and Mars are markedly "non-concentric" so the two planets continue to draw nearer even after opposition. At the point of closest approach (11h UT on the 16th), Mars will be 0.40358 astronomical units (60.537 million kilometers) distant and will have a disk 23.2" across. This is the best Mars opposition since 1973. (See last month's Gazer's Gazette for full observing details.)

Minor Planets

1 Ceres (magnitude 8.3) lies to the south of Denebola, Beta (β) Leonis. Its positions:

1st:	11h 31m 47s,	13° 15.5′
10th:	11h 42m 51s,	11° 34.3′
20th:	11h 55m 47s,	9° 39.5′
30th:	12h 09m 17s,	7° 43.1′

Ceres sets about 11 p.m. local daylight time on the 15th.

2 Pallas is too close to the Sun to be

Brian Donovan's shot of Halley's Comet and the southern Milky Way on March 19, 1986, is this month's $100 "Best Astrophoto" award winner. The photo was taken with a 28mm piggybacked lens at f/2.8, high-speed color film, and a 4-minute exposure.

seen this month.

3 Juno (10.6) lies in Serpens Caput, close to the 3rd-magnitude stars Delta (δ) and Epsilon (ε) Ophiuchi. Its positions:

1st: 16h 16m 58s, −3° 34.8′
10th: 16h 12m 36s, −3° 54.3′
20th: 16h 09m 36s, −4° 26.0′
30th: 16h 08m 38s, −5° 06.0′

Juno sets around 3:30 a.m. local daylight time on July 15.

4 Vesta (7.4) is moving eastward in north-central Cetus. Its positions:

1st: 0h 50m 12s, −2° 02.1′
10th: 0h 59m 24s, −1° 38.1′
20th: 1h 08m 00s, −1° 25.0′
30th: 1h 14m 36s, −1° 27.4′

Vesta rises around 1 a.m. local daylight time on the 15th.

To locate a minor planet, plot its dated positions (given for 0h UT) lightly in pencil on a good star atlas (*Sky Atlas 2000.0*, for example) and sketch a smooth curve linking the points. Then observe the starfield at low magnification and photograph or plot by hand what you see. Check the field a night or two later; the "star" that moved is it. (All minor planet coordinates are for the epoch 2000.0.)

Jupiter

As the four Galilean moons sweep endlessly around Jupiter, they periodically enter and emerge from the invisible cone of shadow that extends from behind the planet. For us to see these events, Jupiter must lie about 90° away from the Sun; only then can we, in a sense, "peep around" the planet.

The inner two moons (Io and Europa) orbit too close to Jupiter to display both phenomena this month. Only their disappearances are visible. With Ganymede and Callisto, however, the reappearance can be viewed as well. Try observing on July 6: at 9h 21m UT, Ganymede will fade as it vanishes into Jupiter's shadow and brighten as it reappears at 12h 50m. Similarly, on the 22nd Callisto will fade from view at 10h 33m and emerge at 14h 13m. If you enjoy watching such sights, see the complete tables of satellite events that are published in the *Astronomical Almanac* every year. (For information on this publication, write to the Superintendent of Documents, Government Printing Office, Washington, DC 20402).

Saturn

Titan is Saturn's largest moon and is quite easy to observe since any optical aid — even binoculars — will reveal it. For a bit more of a challenge, try looking for Rhea, the next moon inward from Titan. Circling Saturn every 4½ days, Rhea is about 1.4 magnitudes dimmer than Titan. Look for it near Titan, to the east of Saturn, around 0h UT on July 2. These two moons will be paired again to the east of Saturn around 23h on the 11th.

Uranus

At opposition early last month, Uranus is now a good object for your telescope in the evening sky. At 6th magnitude, it is easy to find about 1° northwest of Omicron (o) Ophiuchi (see the finder chart in the January 1986 issue). Uranus has a vivid blue-green disk 3.9″ across.

Neptune

Also at opposition in June, Neptune is very well placed for observing in the evening sky until early autumn. At 8th magnitude, it is substantially dimmer than Uranus and sports a smaller, less recognizable disk 2.3″ across. During July, locate it by pointing your telescope 30′ north of the Trifid Nebula (M-20) and then sweeping it slowly to the east a distance of about 10 minutes of right ascension (2.5°). At medium magnification, look for a small gray disk that appears non-stellar.

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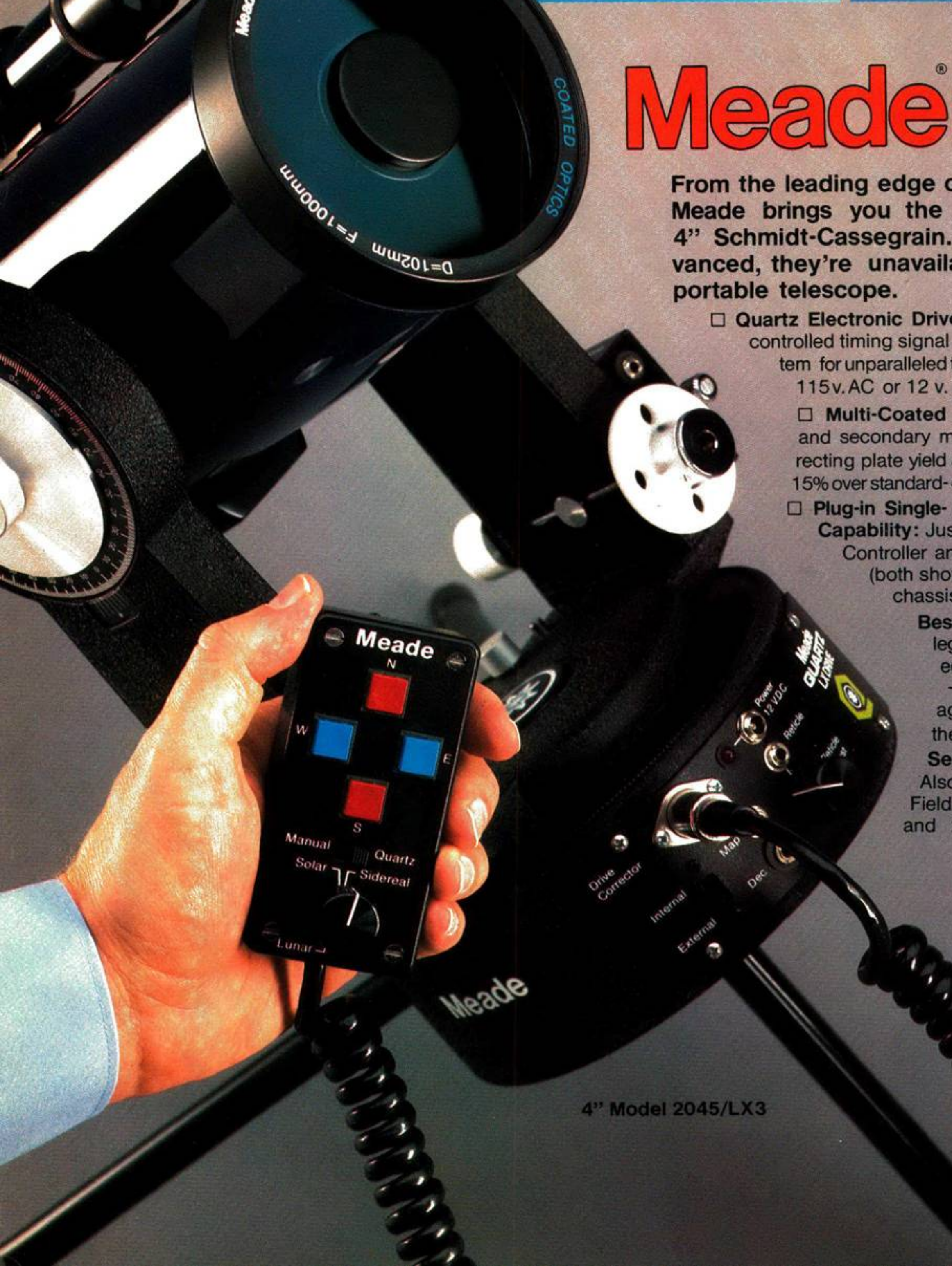

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Models 2080/GEM and 2120/GEM (with **G**erman-type **E**quatorial **M**ounts) include the same optical tube assemblies as Meade fork-mounted Schmidt-Cassegrains, but at more affordable price levels. Consider these *standard* features:

German-type Equatorial Mounts with Dual Worm-Gear Controls: Large, stable mountings with easy-to-reach controls for smooth, effortless tracking, yet which transport readily for use in the field. Internal polarscopes are included for precise polar alignment.

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Series 4000 Super Plössl 26mm (a $120 eyepiece): For exquisite telescope images at 77X (2080/GEM) or 96X (2120/GEM).

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OPTIONAL FEATURES

#784 Quartz Motor Drive: DC powered, for fully automatic sidereal tracking and push-button R.A. drive correction.

#3000 Computer Control System: Includes pulse motors and optical encoders on both telescope axes for automatic slewing and object-location from an extensive pre-programmed library of deep-space objects. See the Meade General Catalog for details on this important option.

New 1986 Meade General Catalog 86-C: $3.00

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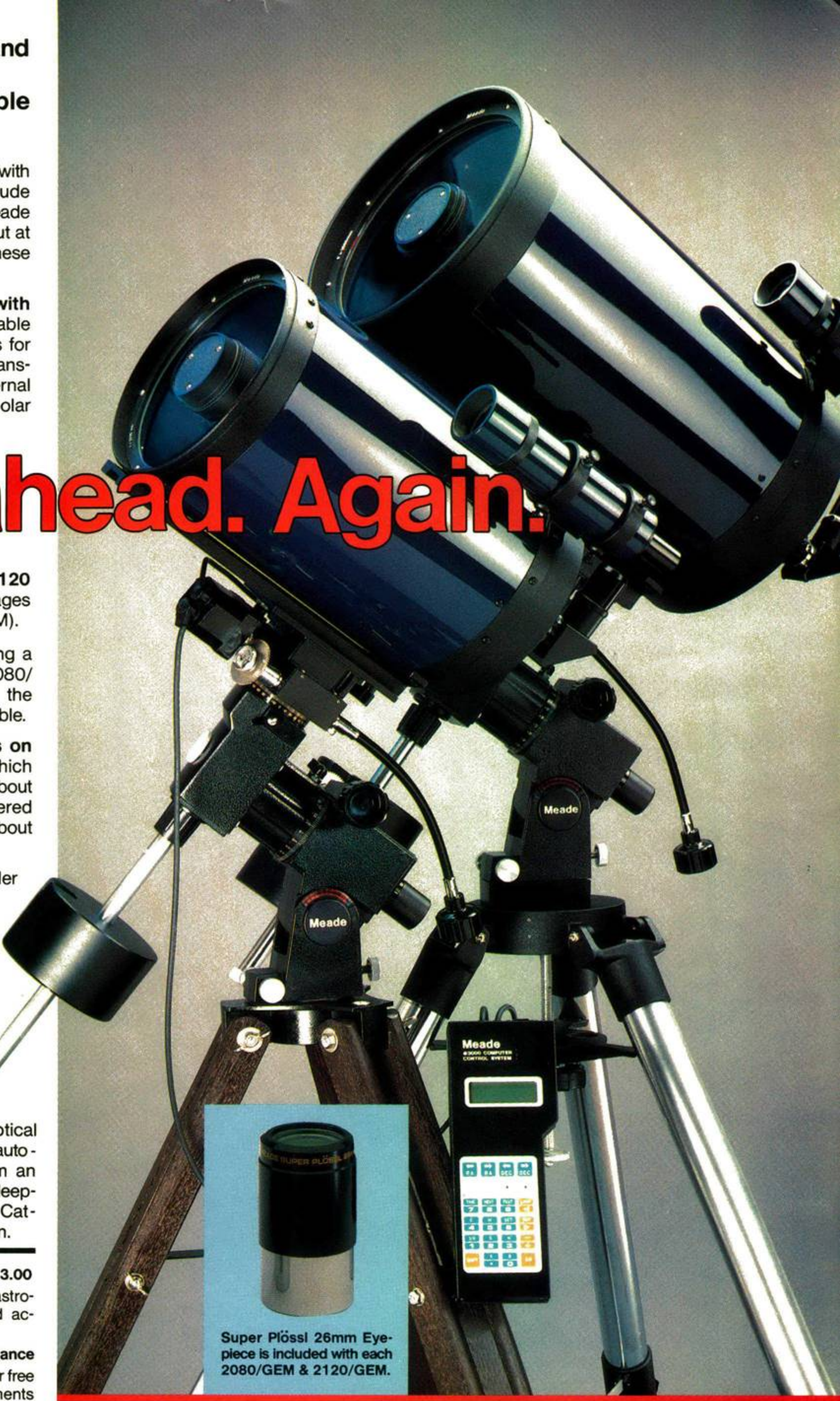

Super Plössl 26mm Eyepiece is included with each 2080/GEM & 2120/GEM.

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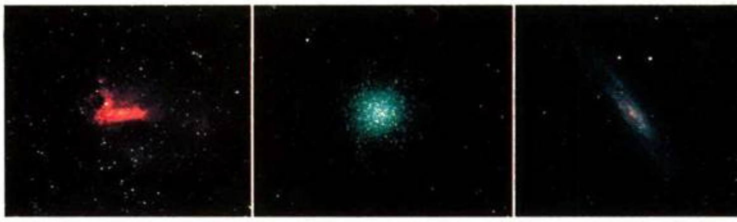
These are slow processes, designed to meet our criteria for telescope performance, not sales performance.



C8 Astrophotographs: M-17, Omega Nebula; M-13, Globular Cluster; NGC-253.

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